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BRADLEY FIGHTING VEHICLE GUNNERY:
An Analysis of Engagement Strategies
for the M242 25-mm Automatic Gun

THESIS

James G. Riley
Captain, USA
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BRADLEY FIGHTING VEHICLE GUNNERY:
An Analysis of Engagement Strategies for the M242 25-mm Automatic Gun

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

James G. Riley, B.S.

Captain, USA

March 1993

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Preface

The purpose of this research was to improve Bradley Gunnery procedures. The study of engagement strategies was undertaken to provide additional guidance for the structure of the 25-mm point target engagement.

A model, based on established US Army Material Systems Analysis Activity (AMSAA) methodology, was used to simulate the gunnery process and provide data output in order to analyze various strategies and procedures. Although limited to the single stationary BMP-type target engagement, the results of the analysis provide definite insight into the structure of an efficient and effective 25-mm engagement.

I wish to credit COL John T.D. Casey with the inspiration for this study. A true student of the Bradley and gunnery in particular, COL Casey taught me to question, analyze, and improve the methods and tools of our chosen profession. I would also like to thank Mr. Ken Hilton and Donna Quirido of AMSAA for their invaluable technical assistance in the development of this thesis. My thesis committee, LTC Kenneth Bauer and Prof. Dan Reynolds deserve special thanks for guiding me through the thesis ordeal and keeping an open mind when exposed to "Army stuff." Lastly, I am forever indebted to my wife Kathy and two sons, Jonathan and Scott, for their patience, understanding and constant support.

James G. Riley

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Abstract

This thesis studies various engagement strategies for the Bradley Fighting Vehicle's 25-mm automatic gun firing APDS-T ammunition against a BMP-type target. The Army currently provides only the broadest guidance for the structure of the 25-mm point target engagement which results in the employment of an assortment of strategies throughout the Bradley community. The goal of this research was to determine if a best method exists.

Bradley gunnery is a complex set commander/gunner interactions which can be difficult to represent with the analytic models commonly found in the literature. A model, based on the simulation methods used by the US Army Material Systems Analysis Activity (AMSAA), was developed to simulate the gunnery process in order to analyze the effects of firing a set pattern of single sensing rounds and multiple round bursts for the purpose of 'killing' the target.

Analysis of variance techniques were used to characterize the effects of engagement strategies, precision and battlesight firing modes, and the burst on target (BOT) direct fire adjustment technique on the simulated Bradley gunnery process. Based on these results, conclusions and recommendations concerning the structure of the 25-mm point target engagement are discussed.

BRADLEY FIGHTING VEHICLE GUNNERY
AN ANALYSIS OF ENGAGEMENT STRATEGIES FOR THE 25-MM GUN

I. *Introduction*

1.1 *Background*

New technology and doctrinal concepts have changed the face of the Army. Our senior planners envision that the nature of modern warfare will lead to future battles of unprecedented scope and intensity. To meet this challenge the Army identifies three essential components to superior performance in combat: superb soldiers and leaders; a sound doctrine for fighting; and the finest weapons and supporting equipment available.

First and foremost, well trained and well led soldiers are the key to victory in future battles just as they have been in the past. The Army places a premium on recruiting quality soldiers and providing the most realistic and demanding training available.

To tell their soldiers 'how to fight', the Army has developed AirLand Battle Doctrine. As described in *Field Manual (FM) 100-5*, AirLand Battle "reflects the structure of modern warfare, the dynamics of combat power, and the application of the classical principles of war to contemporary battlefield requirements" (7:9). A key aspect of this doctrine is its focus on combined arms operations; the coordinated use of Armor, Infantry, Field Artillery, Army Aviation, and Air Force Close Air Support (CAS) to

maximize the tremendous lethality of numerous weapon systems and destroy the enemy.

To provide the best weapons and equipment for American soldiers to fight with on the modern battlefield, the Army has developed new systems for each of the major combat arms: the M1 Abrams main battle tank; the AH-64 Apache attack helicopter; the multiple launch rocket system (MLRS); and, the subject of this research, the M2 Bradley infantry vehicle. (7:5-7)

The Bradley Fighting Vehicle (BFV) is a fully-tracked armored combat vehicle armed with two Tube-launched, Optical-tracked, Wire-guided (TOW) anti-tank missile launchers, a 25-mm bushmaster chaingun, and a 7.62mm coax machine gun. It is also capable of carrying a six man infantry squad inside. As a weapons platform, the Bradley can engage and destroy all known armor threats out to 3750 meters using the TOW missile. The 25-mm chaingun can fire two types of ammunition: armor piercing discarding sabot (APDS) with an effective range of 1700 meters and high-explosive incendiary (HEI-T) with an effective range of 3000 meters, allowing it to engage lightly armored vehicles, unarmored vehicles, or suppress crew served weapons positions. The coax machine gun has an effective range of 900 meters and can be used to engage dismounted infantry or suppress crew served weapons positions. As a personnel carrier, the Bradley provides excellent protection for the

infantry squad from indirect and small arms fire. The squad can also quickly dismount to perform traditional infantry missions.

The Bradley was originally designed as the replacement for the M113 family of armored personnel carriers which were the primary means of transportation for infantry personnel assigned to heavy divisions during the late 60s and the 70s. Two events changed the original concept.

In 1967, the Soviets fielded the BMP (*Bronevaya Maschina Piekhota*); a fully tracked armored amphibious infantry combat vehicle with a turret mounted 73mm smoothbore gun and a 7.62mm coax machine gun. Additionally, a turret mounted launching rail for the SAGGER anti-tank guided missile provided the BMP with the capability to effectively engage tanks out to 3000 meters. It also had a troop compartment for eight infantrymen complete with firing ports which allowed them to fire their assault rifles from inside. The BMP represented a transition from the 'armored personnel carrier' to the 'infantry combat vehicle' in the Soviet and most Warsaw Pact armies. The Soviets appeared to have a revolutionary new capability to wage rapid combined arms offensive operations with tanks, self-propelled artillery, and the BMP. The second event was the 1973 Yom Kippur War. During the war, anti-tank guided missiles (ATGM) proved to be extremely effective tank killers at ranges beyond 3000 meters. In an effort to offset the

perceived Soviet advantage with the BMP and capitalize on existing ATGM technology, the Bradley design was altered to incorporate the TOW missile system and create an effective match for the BMP. The original one-man turret design gave way to a two-man version to allow the mounting of a twin TOW launcher. The sophisticated sighting system for the TOW was integrated, which also greatly enhanced the engagement capabilities of the 25-mm gun. The troop compartment shrank as a result, thereby cutting the number of infantrymen from eleven to six. It was generally believed, however, that the improved firepower of the new configuration was an acceptable tradeoff. (9:185-201)

1.1.1 25-mm Chain Gun, M242. The main armament of the Bradley Fighting Vehicle (BFV) is a 25-mm, fully automatic, externally powered bushmaster chain gun. It is used to destroy lightly armored vehicles: specifically the BMP (5:1_2). The gun is capable of firing two types of ammunition; armor-piercing discarding sabot with tracer (APDS-T) and high-explosive incendiary with tracer (HEI-T). APDS-T is the appropriate ammunition for engagements against the BMP. At one time, it was commonly believed that six APDS-T rounds impacting on a BMP would render it combat ineffective. In addition to these six rounds, two additional sensing rounds were allocated for a total of eight rounds per single engagement. For training purposes, the same number of rounds (8) are allocated for each

engagement; however, the number of hits required to simulate a 'kill' is reduced to three rounds (4:10_47). The 25-mm is also capable of three rates of fire: (1) single shot - as fast as the Bradley Commander or gunner can pull the trigger, (2) low rate - 100 rounds per minute, plus or minus 25 rounds, and (3) high rate - 200 rounds per minute, plus or minus 25 rounds. In the broadest terms, an engagement strategy is a specific combination of single shots and/or multiple round bursts totaling eight, fired at a particular rate in order to destroy an identified target.

The sighting and weapons control component for the 25-mm gun is the Integrated Sight Unit (ISU).

> The gunner and commander use the integrated sight unit to locate, identify, range and engage targets day and night. The ISU is moved with the turret in azimuth and follows weapons elevation by means of a servo driven mirror that is electrically linked to the selected weapon's rotor movement. ... In gun mode, the mirror follows the gun rotor elevation/depression. 25-mm boresight adjustments in elevation moves the mirror to align with the 25-mm. Azimuth adjustment moves the aiming reticle. ... The sighting mirror is further adjusted for superelevation by dialing in estimated range. (Superelevation is used to maintain weapon accuracy by adjusting the mirror line-of-sight in elevation to allow for trajectory of the selected ammunition.) ... The gunner's estimate of range is dialed into the sight which lowers the weapon to realign on target. Superelevation is stepped in 200 meter increments and is displayed in the gunner's and commander's eyepieces ... (8:44).

1.1.2 Bradley Fighting Vehicle Gunnery. Unfortunately, range to the target must be visually estimated. The Bradley gunner's or commander's ability to accurately determine the range to a target is dependent on

the tactical situation. In a defensive scenario several passive range determining methods can greatly increase the crews capability. Target reference points, at known distances within an established sector of fire, allow the crew to quickly and accurately range the target. The reticle within the ISU also has a horizontal ranging stadia (choke sight) which can be used to determine the range to BMP type vehicles. The stadia lines are horizontally spaced to represent the visual size of a 1.8 meter high vehicle at various ranges from 500 to 3000 meters. Figure 1.

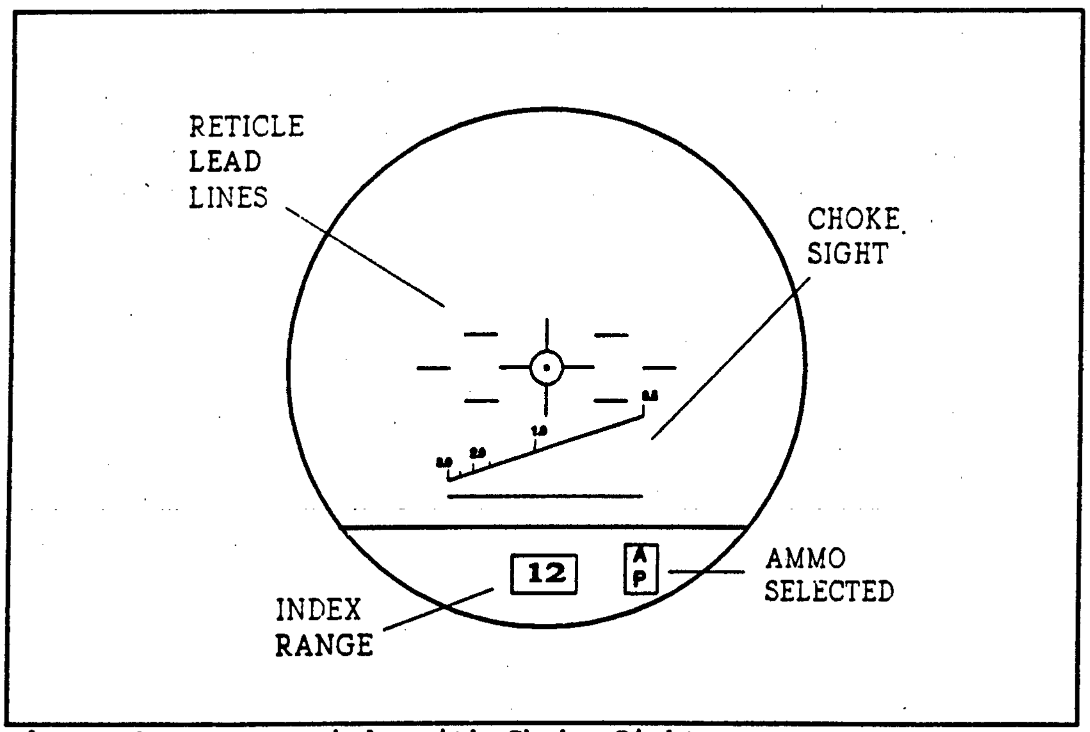


Figure 1. ISU Reticle with Choke Sight

A final method makes use of the relationship between the reticle in standard military binoculars and the mil unit of angular measurement. A quick reference table with various mil and range relationships is commonly used by Bradley commanders to determine the range to a vehicle target identified with binoculars. The principal drawback to these methods is the amount of time required to apply them. Because defensive operations usually provide a higher degree of concealment and protection from enemy fire, the time is usually available. *FM 23-1, Bradley Fighting Vehicle Gunnery*, specifically limits the use of these methods to the defense (4:3_17-3_21). Offensive operations are entirely different: time is absolutely critical!

FM 23-1 also defines two types of fire commands which reflect either a defensive or offensive engagement: precision and battle sight.

> Precision fire is the most accurate type of direct fire. Precision gunnery techniques should be used only when time permits, such as when the (Bradley) vehicle is in a defensive position or in an overwatch position. ... Once a target is acquired, the Bradley commander issues a precision fire command. Once the gunner or Bradley commander has identified the target, he ranges to the target as accurately as possible and announces that range. ... Battle sight is a gunnery technique that can be used in a most-dangerous surprise situation. It is not as accurate as precision gunnery techniques; but battle sight gunnery is the quickest way to engage the enemy before he can fire. (4:4_5)

Battlesight is a planned engagement that assumes the most likely threat is the BMP and the most likely range to that threat will be 1200 meters. The first assumption is

obvious. The second attempts to make the best use of the ballistic characteristics of the APDS-T round. The ISU and the gun are zeroed to this range to give the highest probability of a first round hit. Zeroing procedures adjust the ISU reticle to establish a definite relationship between the trajectory of a particular round and the line of sight to the target at a specific range (4:2_1). The range assumption leaves a large opportunity for error between the actual range to a threat target and 1200 meters. If the crew is able to determine that the range to the identified target exceeds 1400 meters, *FM 23-1* recommends that the gunner index 1600 meters (extended battlesight) to increase the probability of a first round hit. The nature of the future battlefield may be the limiting factor on the crew's ability to do so.

> Bradley platoons must be prepared to move and to rapidly engage multiple targets. Platoons will be operating within irregular battle lines. Depending on the tactical situation and the area of operations, Threat targets will be intermixed with friendly and neutral (civilian) vehicles. ... Survival depends on the platoon's ability to search for, acquire, classify, confirm, and rapidly engage Threat targets. Bradley platoons must take advantage of the situation and fire first. (5:3_1)

This type of 'pressure packed' environment creates some doubt as to whether even this minimal amount of range estimation will take place. Although ranging errors can also creep into a defensive engagement, they would logically be much smaller as long as one of the various range determination methods is used. To correct for these

inherent ranging errors a direct fire adjustment technique called burst on target is most often used.

Burst on target (BOT) uses the observed impact of the rounds from a combination of single shots (sensing rounds) and multiple shots (killing bursts) to guide the strike of the round onto the target. If the first round fired at a target fails to hit it, the gunner and vehicle commander observe where the round strikes in relation to the target and convert the relationship into an executable correction for the original point of aim. Corrections are normally given relative to the size of the target; "up 1/2 target form, right one target form", etc. The adjustment procedure is repeated until a round impacts on the target, at which time the verbal correction is replaced by the command "target". This command directs the gunner to continue to engage the target with 3-5 round bursts until it is destroyed or the command "cease fire" is given. Each of these killing bursts are also observed and corrected as necessary (4:4_19).

1.2 Problem Statement

FM 23-1 currently provides only the broadest guidance for the structure of the 25-mm point target engagement. "The gunner fires a sensing round, announces his observation and adjusts rounds by BOT. The gunner then fires a three to five-round burst on the target. He continues firing bursts

until the target is destroyed or the command CEASE FIRE is given (4:4_12)." Consequently, every Bradley unit has developed it's own 'engagement strategy': a specific combination of single shots and/or multiple round bursts totaling eight, fired at a particular rate in order to destroy an identified target. The effectiveness of possible engagement strategies and those currently in use throughout the Army may vary significantly and should be evaluated.

1.3 Research Objective

The purpose of this research is to identify the best engagement strategy for the 25-mm gun, if one exists, so that Bradley gunners will become more efficient at engaging and destroying threat targets.

1.4 Assumptions

The underlying assumption of the Bradley 25-mm point target engagement is that eight rounds is the appropriate number required to kill a single BMP. The Army Material Systems Analysis Activity (AMSAA) is currently quoted as the source for this estimate of eight rounds per BMP target. According to analyst Donna Quirido, AMSAA does not provide or support any such estimate (30). The true source of this estimate is currently unknown.

Despite the questionable validity of the eight rounds to kill a BMP estimate, this number will be the assumed

length, in rounds fired, of a point target engagement. Bradley gunnery training and evaluation outlined in *FM 23-1* revolves around this number. Until this estimate is officially modified, any analysis of engagement strategies must reflect this current 'truth.' Operationally, the crew will undoubtedly continue to fire at the target until the desired effect is achieved. *FM 23-1* states that "the minimum standard is to achieve a mobility or firepower kill. ... the Threat vehicle can no longer move under its own power. ... *(or)* can no longer use its weapon systems" (5:4_32). It is assumed that a gunner will 'expand' the initial eight round engagement with repeated multiple round bursts of equal length until the desired target effect is obtained.

1.5 Research Questions

Based on the assumptions noted above, the research will focus on answering the following questions: 1. What is the best engagement strategy for the BFV 25-mm firing APDS-T ammunition at a BMP type point target? 2. What is the most efficient burst size for expanding the initial engagement strategy to achieve the desired target effect? The first question deals with the first eight rounds fired at the target, either in training or in real battle. The second question addresses the operational environment, where kill effect on an actual armored vehicle determines the end of the engagement. The answer to these questions will provide

additional training guidance to Bradley units as they prepare for their wartime missions during gunnery exercises.

1.6 Scope

This research will focus on the point target engagement using the M791 APDS-T round. The newer M919 armor-piercing, fin stabilized discarding sabot with tracer round (APFSDS-T) lacks sufficient live-fire testing to be included in this analysis. The increased muzzle velocity and maximum effective range (classified) of the 919 round may produce significantly different results or merely extend the target range considerations. Based on unclassified information about the new round in *Armed Forces Journal International*;

> Ballistically identical to the M791 ..., the M919 allows the Bradley to defeat thicker armor at greater range than previous rounds. *(As a result of)* ... improved depleted uranium (DU) penetrator and propellant technologies for the round. (19:22)

the latter assumption appears to be the case.

The M792 HEI-T round will not be considered. The round-to-round random dispersion of the HEI-T is significantly greater than that of APDS-T which would presumably lead to significantly different results (2:11-12). Since HEI-T is predominately used for suppression, no attempt will be made to determine an overall best engagement strategy for both types of ammunition.

Every effort will be made to consider all feasible engagement strategies. A letter submitted to the January-February issue of *INFANTRY* magazine requested input from the Bradley community so that no engagement strategy currently in use will be inadvertently overlooked (32:1).

Based on the assumption regarding additional killing bursts fired after the initial eight rounds to achieve a desired target effect, the research will include an analysis of three, four, and five round burst patterns to determine if the length of burst is significant. Bursts of more than five rounds will not be evaluated based on readily available ammunition considerations.

1.7 Limitations

The model used in this research will simulate the 25-mm point target engagement of a stationary Bradley Fighting Vehicle against a BMP sized stationary target only. With its fully stabilized gun, the Bradley is certainly capable of effectively engaging targets while stationary and on the move. Threat vehicles will also be either stationary or moving on the battlefield creating numerous stationary-on-moving and moving-on-moving types of engagements. However, the single scenario used in this research should provide an indication as to whether the use of a particular engagement strategy might be advantageous. The enumerable combinations of moving and stationary aspects could then be simulated,

perhaps in the Unit Conduct of Fire Trainer (UCOFT) environment, to determine if the use of a set engagement strategy remains feasible and/or warranted.

1.8 Thesis Organization

Chapter 2 is a literature review that summarizes pertinent information about weapon systems modeling and simulation. Chapter 3 discusses formulation of the simulation model. It also provides detailed documentation of the simulation and discussion of the algorithms used to model the 25-mm engagement process. Chapter 4 reviews the research methodology and evaluation of model results. Chapter 5 presents the analysis and findings from the model output. Lastly, Chapter 6 concludes the thesis and presents recommendations for further study.

II. *Literature Review*

The purpose of this literature review is to research weapon systems modeling techniques in order to develop a detailed and accurate model representation of the 25-mm gun system. This model will be the analytic tool used to compare and eventually rank various engagement strategies. Obviously, conclusions drawn from an invalid model would be of no use to the Army. Bradley gunnery techniques were described in Chapter 1. The discussion covered the topic only to the level necessary to understand how the vehicle crew functions during an engagement. The technical aspects of the 25-mm gun system were also addressed in detail sufficient to outline the key functions to be modeled and how the gun/sighting system works. The modeling methods for the various factors represented in the Bradley gun system will be outlined without extensive historic or theoretical background. The methods presented are those generally accepted by the Army Material Development and Readiness Command, summarized in *DARCOM Pamphlet 706-101*, and should therefore not require a more rigorous theoretical justification (6). The review is divided into three major parts: definitions, single round accuracy modeling, and multiple round accuracy modeling. The first section will define the various terms and concepts involved in weapon systems modeling and ballistics. The second section will

focus on basic models that determine whether a single round fired will hit the target, while the last section will address models for engagements in which multiple rounds are fired at a single target.

2.1 *Definitions*

In his *Lecture Notes in High Resolution Combat Modelling,* James K. Hartman notes that

> two basic principles are invoked in nearly all accuracy models: 1. Weapon accuracy can be adequately described by considering the projectile impact point to be a random variable. 2. The Normal probability distribution is a good model for the random impact points. (15:7_2)

There are numerous components to the weapon delivery errors which are described by the normal distribution. Figure 2 graphically shows the various error components of weapon system accuracy.

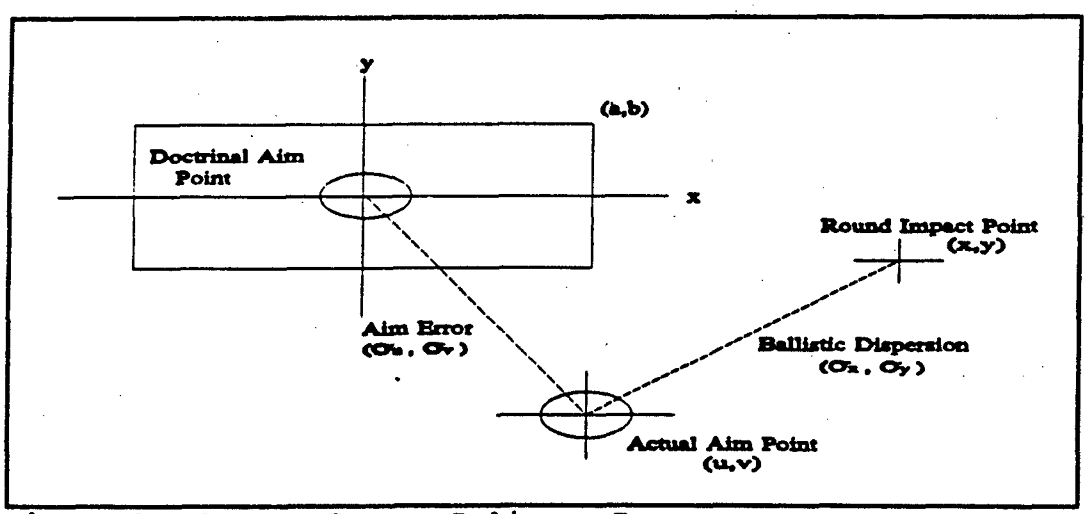


Figure 1. Weapon System Delivery Errors

2.1.1 Ballistic Dispersion. In his article, *On the Computation of Hit Probability*, Hermann Josef Helgert states,

> ballistic dispersion is the combined effect of round-to round variation in shell manufacture, powder weight, moisture content and temperature, and short-term variations in the state of the atmosphere at the instant of firing. In this list must be included a factor peculiar to guns mounted on unstable platforms such as ships, namely round-to-round variations in range and deflection caused by transitional motion of the gun barrel at the instant of firing, and the nature of the recoil of guns mounted on such unstable platforms. It is commonly assumed, and there is good supporting experimental evidence, that ballistic dispersion is a Gaussian random process with zero mean and negligible correlation between rounds. (16:670)

Ballistic Dispersions are thus defined by the relations:

$$\begin{aligned} E(x) &= 0 \\ Var(x) &= \sigma_x^2 \end{aligned} \tag{1}$$

$$\begin{aligned} E(y) &= 0 \\ Var(y) &= \sigma_y^2 \end{aligned} \tag{2}$$

2.1.2 Aim Errors. Aiming errors are errors in determining the correct gun elevation and azimuth required for the round fired to hit the Doctrinal Aim Point. The Doctrinal Aim Point is the center of the visible target area. The Actual Aim Point is the point on or near the target where the weapon is aimed at the instant of trigger pull. Aiming errors are the difference between the two points. They are further categorized as systematic errors and time varying errors. The total aim error in the horizontal (x) and vertical (y) axes about the Doctrinal Aim Point for the *ith* shot can be expressed as:

$$u_i = u(t_i) + u(b_i) \quad (3)$$

$$v_i = v(t_i) + v(b_i) \quad (4)$$

where

u(b) = x component of systematic error (bias)
v(b) = y component of systematic error (bias)
u(t) = x component of time variable error
v(t) = y component of time variable error

Errors in determining the range to a target or the correct location of the visible center mass point are systematic. Helgert states:

> The net effect of the systematic errors is to impart a constant bias to the center of the impact points of the rounds. One's lack of knowledge of the exact value of the constant is expressed by taking it to be a sample function from another Gaussian random process with zero mean ... (16:670)

The time varying errors in gun elevation and azimuth are due to the gunner's inability to hold his aim point steady throughout the engagement or in the case of the Bradley, stabilization inaccuracies. According to Helgert:

> These errors give rise to aim-wander, a term that derives from the fact that the path traced by the intersection of the gun barrel mean line of sight and a plane perpendicular to it would, as a function of time, appear to be wandering in a more or less random fashion. The effect of the resulting sequence of aim points at the target is another nearly Gaussian process with time-varying means and auto-correlation functions. ... Aim wander ... is the cause of the well known round-to-round correlation of impact points that may exist in high-rate-of-fire guns. (16:670-571)

This time varying component of aiming error, or assumptions regarding it, are a significant aspect of modeling multiple round bursts of fire. It is assumed that ballistic dispersion and aim errors (systematic and time varying) are independent and also additive (16:671).

2.1.3 Total Dispersion. Based on the assumption that the distribution of rounds is approximately Normal, the probability density function (pdf) describes the coordinate components of total dispersion (6:13_6):

$$f(X) = [1/(\sqrt{2\pi}\,\sigma_x)]\exp[-(x-u)^2/(2\sigma_x^2)] \tag{5}$$

$$f(Y) = [1/(\sqrt{2\pi}\,\sigma_y)]\exp[-(y-v)^2/(2\sigma_v^2)] \tag{6}$$

where

u = x coordinate of Actual Aim Point

v = y coordinate of Actual Aim Point

2.2 Single Round Accuracy Models

Single round hit probability models are categorized as either centered aim point or offset aim point in *DARCOM PAMPHLET 706-101* depending on whether aiming errors are equal or not equal to zero. The pamphlet also presents the models in terms of either circular or rectangular target form. (6:14_1-14_20) Since the BMP silhouette most closely approximates a rectangular target, only the equations of this form will be covered here. However, Frank E. Grubbs, of the US Army Ballistic Research Laboratories, asserts that the computed probability of hitting a circular target is not significantly different from the results assuming a rectangular target for many practical applications, "since available vulnerability data or lethality data or other

input information may lead to some lack of precision anyway" (14:58).

2.2.1 Probability of Hitting a Rectangular Target Centered at the Origin. Figure 3 depicts a rectangular target where the Actual Aim Point is the true center of mass. Aiming errors are assumed to be zero.

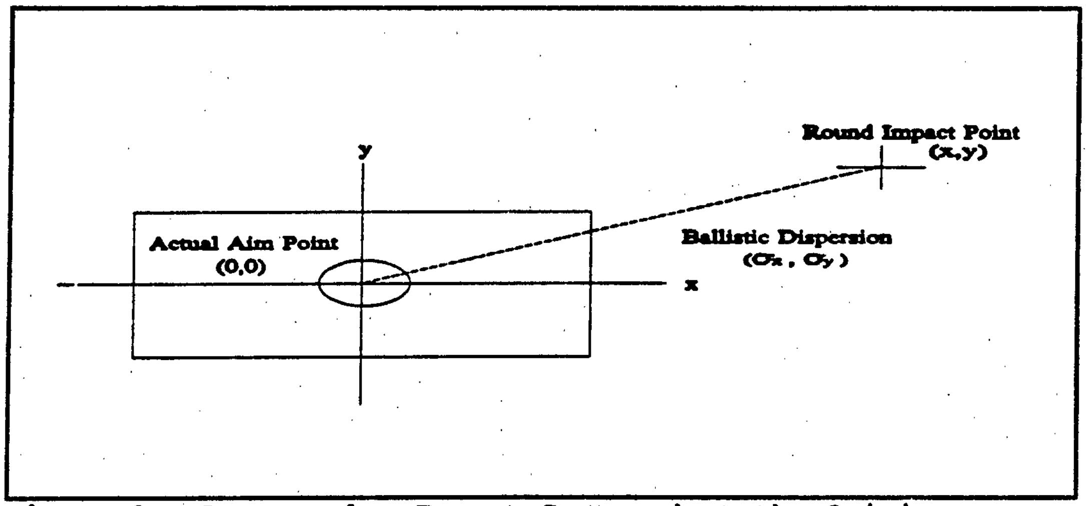


Figure 2. Rectangular Target Centered at the Origin

The chance of hitting a rectangular target centered at the origin is the product of equations (5) and (6) integrated over their respective coordinate intervals (6:14_4).

$$p(h) = \left[1/(\sqrt{2\pi})\int_{-a/\sigma_x}^{a/\sigma_x}\exp(-x^2/2)\,dx\right]\left[1/(\sqrt{2\pi})\int_{-b/\sigma_y}^{b/\sigma_y}\exp(-y^2/2)\,dy\right] \quad (7)$$

2.2.2 Offset Probabilities of Hitting. Offset aim point models take ballistic dispersion as well as systematic aiming errors into consideration. Figure 2 depicted this more probable engagement situation. If the coordinates of

the Actual Aim Point are known the hit probability model becomes (6:14_17):

$$p(h) = [1/(2\pi)] \int_{(-a-u)/\sigma_x}^{(a-u)/\sigma_x} \int_{(-b-v)/\sigma_y}^{(b-v)/\sigma_y} \exp[-(x^2+y^2)/2]\, dxdy \quad (8)$$

Unfortunately, the aim point at trigger pull is hardly ever known, consequently Grubb notes that if credible aim error estimates exist, the total aiming error expressed as standard deviations may be included in equation (8) to obtain a solution (14:57).

2.2.3 Approximation Methods. The probability models presented thus far appear fairly simple, however, "the mechanics associated with the integration are extremely cumbersome and no closed form solution is available" (16:673). Two of the most common approximate solution methods are the Polya-Williams Approximation and the von Neumann-Carlton Diffuse Target Concept.

2.2.3.1 Polya-Williams. The Polya-Williams Approximation relates

> the actual probability content of the normal distribution to an exponential function by comparing probabilities of hitting a square target with that of a circular target of the same area. (6:14_5)

The resulting approximation to the truncated normal integral has a maximum relative error of 0.0075. Using Polya-Williams, an approximate solution to equation (7) can be calculated by (6:14_6):

where

$$p(h) \approx \left[\{1-\exp[-2a^2/(\pi\sigma_x^2)]\}\{1-\exp[-2b^2/(\pi\sigma_y^2)]\}\right]^{1/2} \quad (9)$$

a = half-target width

b = half-target height

2.2.3.2 von Neumann-Carlton Diffuse Target

Concept. According to the summary in *DARCOM-P 706-101* (6:14_12-14_17)

> the so-called 'diffuse target' concept of von Neumann and Carlton involves the use of the normal or Gaussian distribution function over infinite limits to replace and 'diffuse' the target, thereby avoiding the complication of truncating the normal integral. ... consider a target, e.g., a square one, of area **A** on one hand and then on the other a negative square exponential fall-off function of the Gaussian form which is to be integrated over infinite limits to give the area **A**. That is, the elementary area, *dxdy*, is weighted by such a function and then integrated. By equating the area **A** of the (square target to the area for the integral, we have
>
> $$A=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\exp[-(x^2+y^2)/(2k^2)]\,dxdy \quad (10)$$
>
> where **k** is a constant to be determined. We find immediately that
>
> $$A=2\pi k^2 \quad \rightarrow \quad k=\sqrt{A/2\pi} \quad (11)$$
>
> Hence, the function which 'diffuses' over infinite limits to give the desired target area **A** is
>
> $$\exp[-\pi(x^2+y^2)/A], \quad -\infty\le x,\ y\le\infty \quad (12)$$
>
> This function is unity at the target center, $x = y = 0$, and decreases to zero as the values of x, or y, or both, increase beyond bounds. Then, for a circular normal delivery distribution, the probability of hitting the 'target' becomes

$$p(h) = 1/(2\pi\sigma^2)\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\exp[-(x^2+y^2)/(2k^2)]\cdot\exp[-(x^2+y^2)/(2\sigma^2)]\,dxdy$$
$$= k^2/(k^2+\sigma^2) = A/(A+2\pi\sigma^2) \tag{13}$$

It is also noted that the von Neumann-Carlton approximation should only be used when the total delivery error is many times larger than the target area **A** (6:14_17).

2.3 Multiple Round Hit Probabilities

Most of the literature concerning multiple round hit probabilities provide results concerning the probability of one hit given that several rounds are fired. Since the 25-mm requires three hits to destroy a target, the desired results are: What is the probability of 1,2,..,5 hits given that a burst of between three and five rounds is fired? Helgert states "it is possible in principle to compute the probability distribution of the number of hits" (16:673) with the equation:

$$P_k(i_1, i_2, \cdots, i_k) = \iint_T \iint_T \cdots \iint_T f_{xy}(i_1, i_2, \cdots, i_k)\, dx(i_1)\, dy(i_1)\, dx(i_2)\, dy(i_2) \cdots dx(i_k)\, dy(i_k) \tag{14}$$

where

k = Number of rounds (i) in the burst

T = Area of the target

As before, however, there is no closed-form solution for this equation. The three most common methods for modeling multiple round hits involve the von Neumann-Charlton diffuse

target approximation, an assumption of Markov-dependence between the rounds fired, or simulating the rounds within the burst separately (15:9_7-9_11; 6:20_16).

2.3.1 The Diffuse-Target Approximation Method.

Multiple rounds tend to exhibit round-to-round dependencies which must be adequately captured by the model. As noted earlier, one of the sources of this round-to-round dependent behavior may be the time variable aiming error. However, as Helgert points out

> if ballistic dispersion is much larger than the time-varying error, the latter may be ignored *(and)* ... the slower the rate of fire, the less will be the correlation between individual aim points and, therefore, between round impact points. (16:674)

The diffuse target approximation method allows the auto-correlated aim points to be captured, however, simplifying assumptions which consider the time varying error to have zero mean and constant correlation can be made.

As in the single shot application of paragraph 2.2.3., a weighting function is applied to the integrand of equation (14) and the limits of integration are extended to infinity. The weighting function used is the two-parameter Gaussian form (11:675-677):

$$g_{xy}(i_1,i_2,\cdots,i_k) = \exp\left\{-\sum_{l=1}^{l=k}[x^2(i_l)/c_x^2+y^2(i_l)/c_y^2]\right\} \qquad (15)$$

where for a rectangular target with sides *2w* and *2h*

$$\begin{aligned} c_x &= 2w/\sqrt{\pi} \\ c_y &= 2h/\sqrt{\pi} \end{aligned} \qquad (16)$$

The approximate solution to equation (14) becomes:

$$P_h(i_1,i_2,\cdots,i_k) = \left|\frac{2}{c_x^2}\Lambda_x+I\right|^{-1/2}\left|\frac{2}{c_y^2}\Lambda_y+I\right|^{-1/2}$$

$$\cdot\exp\left(-1/2\left\{u_x^T\left[\Lambda_x^{-1}-\Lambda_x^{-1}\left(\frac{2}{c_x^2}\Lambda_x+I\right)^{-1}\right]u_x+u_y^T\left[\Lambda_y^{-1}-\Lambda_y^{-1}\left(\frac{2}{c_y^2}\Lambda_y+I\right)^{-1}\right]u_y\right\}\right)$$

where

Λ = the covariance matrices for the x and y components of the possible target impact points

u = matrices for the x and y components of the time-varying mean aim points

I = the identity matrix

Helgert concludes that:

> Whenever the target dimensions are small compared to the total dispersion in the impact points of the rounds, the diffuse-target method of analysis provides an excellent approximation to the hit distribution. (16:677)

Unfortunately, this method remains quite complex and does not allow for a direct representation of the BOT aim point adjust process between single and multiple round bursts (16:674-677).

2.3.2 Markov Dependent Rounds Model. Helgert, Hartman, and *DARCOM Pamphlet 706-101* present models where the round-to-round dependence within a burst is described by

a Markov Chain. (16:680-684; 15:9_9-9_11; 6:20_21) The assumption is made that the probability of a round hitting the target is only dependent on whether the round immediately preceding it hit the target.

> If the conditional probabilities ... are independent of i, the sequence of rounds forms a homogeneous, irreducible Markov chain with ... k-step conditional hit probability: (16:682)

$$\begin{array}{c} \\ 1 \\ H \\ M \end{array}\begin{array}{c} \begin{array}{ccc} 1 & H & M \end{array} \\ \begin{bmatrix} 0 & p & 1-p \\ 0 & p_1 & 1-p_1 \\ 0 & p_0 & 1-p_0 \end{bmatrix} \end{array} \tag{18}$$

or the equivalent

$$p(H_i \mid H_{i-1}) = p + (1-p)(p_1-p_0)^k \tag{19}$$

$$|p(H_i|H_{i-1}) - p(H_i|M_{i-1})| < 1 \tag{20}$$

where

p_1 = the chance of hit on ith round if the $(i-1)$st round is a hit
p_0 = the chance of hit on ith round if the $(i-1)$st round is a miss
$p = p_0/(1-p_1+p_0)$
H = hit
M = miss

J. S. Rustagi along with R. C. Srivastava and Richard Laitinen respectively present two methods for estimating the parameters in the Markov dependent firing distribution using either maximum likelihood estimates or the method of moments. Both methods make use of the probability

distribution of the number of Bernoulli trials required to obtain a preassigned number of successes. If the sequences of the trials are completely known, the maximum likelihood estimates can be used. However, if only the total number of rounds fired to obtain *m* hits is known, the method of moments approach can be used to estimate the desired parameters (34:1222-1227; 33:918-923).

2.3.3 Simulation methods. Hartman notes that the "complexity" of the von Neumann-Carlton and Markov approaches "can be avoided almost trivially if we can afford to simulate each round separately" (15:9_8). A common simulation model is the 'shotgun' or 'two-distribution' model which assumes that total aiming error is constant for all the rounds fired within a burst. The underlying procedure, as listed by Hartman, for models of this type is:

> 1.) Sample once from the aim error distribution to determine the actual aim point, (*u*,*v*), to be used in common for all *N* rounds.
> 2.) For each of the *N* rounds, sample from the ballistic error distribution giving the error (*x*,*y*) and compute the actual impact point for (each) round i as (*u*+*xi*,*v*+*yi*).
> 3.) For each of the *N* rounds, do target geometry computations to determine whether round *i* hit the target ... (15:9_8-9_9)

Ground Warfare Division (GWD), AMSAA currently uses this method to represent the Bradley 25-mm cannon in their HITPROB2 simulation model. The Ground Warfare Division has responsibility for conducting firepower analysis of the Bradley Fighting Vehicle against threat lightly armored vehicles. Their results serve as inputs for U.S. Army

TRADOC models in the form of hit probabilities, kills per burst, and single shot kill probabilities. This effort is conducted in four phases; first round delivery, subsequent fire delivery, projectile lethality, and overall effectiveness during an engagement. The first two phases are of particular interest in this research.

The purpose of the first phase is twofold; to predict first round hit probabilities for the 25-mm round throughout the spectrum of potential engagement ranges and determine the need for a range-in process. The range-in process is defined as:

> The process used by gunners to adjust fire on the target. The range-in process is necessary for weapon systems with limited fire control, since the gunner must correct for errors associated with target range estimation, vehicle cant, wind, system biases, etc. The gunner achieves more accurate fire by adjusting the aimpoint in response to the perceived impact location of the preceding round. (29:1-2)

AMSAA uses the PH1 model for this analysis which will be discussed in greater detail in Chapter 3. First round hit probabilities for the M791 APDS round, as determined by PH1, are listed in Table 1. The relatively low probability of a first round hit beyond 1000 meters supports the need for a range-in process in Bradley 25-mm gunnery.

Table 1

First Round Hit Probability - M791 APDS Ammunition
25-mm M242 Gun versus 2.3 x 2.3 Meter Target
(2:16)

Range (m)	Hit Probability
400	0.92
800	0.74
1000	0.58
1200	0.43
1500	0.26
1600	0.22
2000	0.11

The purpose of the second phase is to evaluate the range-in and the fire-for-effect processes. As previously defined, the fire for effect process reflects the successive firing of multiple round bursts at the target until the desired level of destruction is achieved. The HITPROB2 model is used to determine the distribution of expected range-in rounds and the fire-for-effect burst dispersions. The burst dispersions are the sum of the burst-to-burst and within-burst dispersions using the 'shotgun' or 'two-distribution' model noted above. See Figure 4.

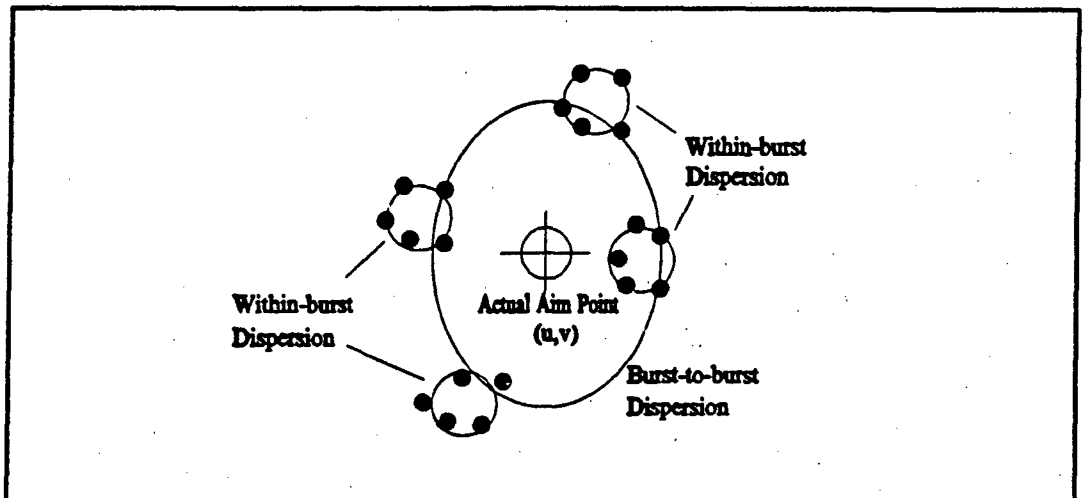


Figure 4. Multiple Round Ballistic Dispersion, Shotgun Model

Within-burst dispersions are the point of impact variation about an aim point for the N successive rounds in the burst. Burst-to-burst dispersions are the variation in the average center of impact for a group of bursts. AMSAA assumes that a five-round burst is used throughout the fire for effect process which is invalid and may prove to be significant based on this research. (29:1-3; 2:7-8, 13-18)

Hartman notes that the simulation approach, despite requiring more computation, has several advantages. Actual target geometry, aspect angle, and degree of defilade/cover can be used. The impact point can be computed relative to the doctrinal aim point for the particular target type, as opposed to always assuming the center of visible target mass. And finally, since the actual impact point is computed, the assumption can be made that target misses are sensed which allows the round-to-round or burst-to-burst

adjustment process to also be modeled. (15:7_26-7_27)

2.4 Conclusion

The Bradley 25-mm gun is a complex system to model in that it requires a range-in process to effectively engage most targets. While this is not unique, given a similar requirement for most machine guns and indirect fire weapons, the Bradley's combination of limited, ready to fire, ammunition and vulnerability when exposed to return anti-armor fires requires an extremely quick and efficient engagement process. The accepted procedure, as discussed in Chapter 1, employs a combination of single rounds and multiple round bursts. The vast majority of the literature on weapon systems modeling deals with separate single and multiple round hit probability computations. While these modeling methods will accurately represent the ballistics and accuracy of the 25-mm gun, only the simulation approach appears to offer the means to capture the burst on target adjustment techniques which are the heart of effective Bradley gunnery.

III. *Model Formulation*

3.1 *Introduction*

This chapter discusses the simulation model formulation and the techniques used to represent the various physical aspects of the 25-mm point target engagement. The simulation approach will be discussed and justified as an appropriate solution method for the problem, followed by a general overview of the simulation model, POINT TARGET ENGAGEMENT. The overview will show how the model represents the various aspects of the actual engagement process.

The model has a SLAM based program shell with FORTRAN subroutines. Each of these routines will be described and documented in order to highlight process logic and how it represents a given aspect of the point target engagement. Flow charts and computer code for the model are presented as Appendices A and B.

In most cases, the techniques used throughout the subroutines are those commonly used by AMSAA, Ground Warfare Division to represent the 25-mm gun system. A portion of *Ground Warfare Division Interim Note G-156* will be reproduced to explain the underlying methodology used throughout the simulation model. The relevant algorithms will be presented along with their underlying theoretical basis.

3.2 *Simulation Methods*

The simulation solution method for a symbolic model according to James K. Hartman, *Lecture Notes in High Resolution Combat Modelling*,

> is the solution method which can best deal with complex, dynamic, high resolution models of force-on-force combat where simplifying assumptions would seriously distort the model's representation of the real world system. (15:1_15-1_16)

A model of the Bradley gunnery process certainly seems to fit into this category. As outlined in Chapter 1, a single 25-mm point target engagement involves a complex set of interactive commander/gunner procedural steps. The implementation of a specific engagement strategy, as opposed to merely firing an eight round continuous burst at the target, further complicates a model representation of the process. The analytic solution techniques outlined in Chapter 2 will not allow a faithful representation of the true system. Hartman states, ...

> simulation is extensively used in military analysis because simulation models are the only models which can include the numerous heterogeneous systems and the complex interactions of force-on-force combat. (15:1-17)

The procedures used by AMSAA to simulate weapon systems accuracy lend themselves to the requirements of this research. Single and multiple round impact points are computed based on the system's inherent dispersions, biases, and ballistic errors. Since the actual impact points are computed, misses that do not impact on the target can be

sensed. Simulation offers the most realistic and useful solution method for the research questions.

3.3 Simulation Model POINT TARGET ENGAGEMENT

The simulation model, POINT TARGET ENGAGEMENT, is designed to represent the Bradley Fighting Vehicle engaging a BMP type target with the 25-mm automatic gun, Figure 5.

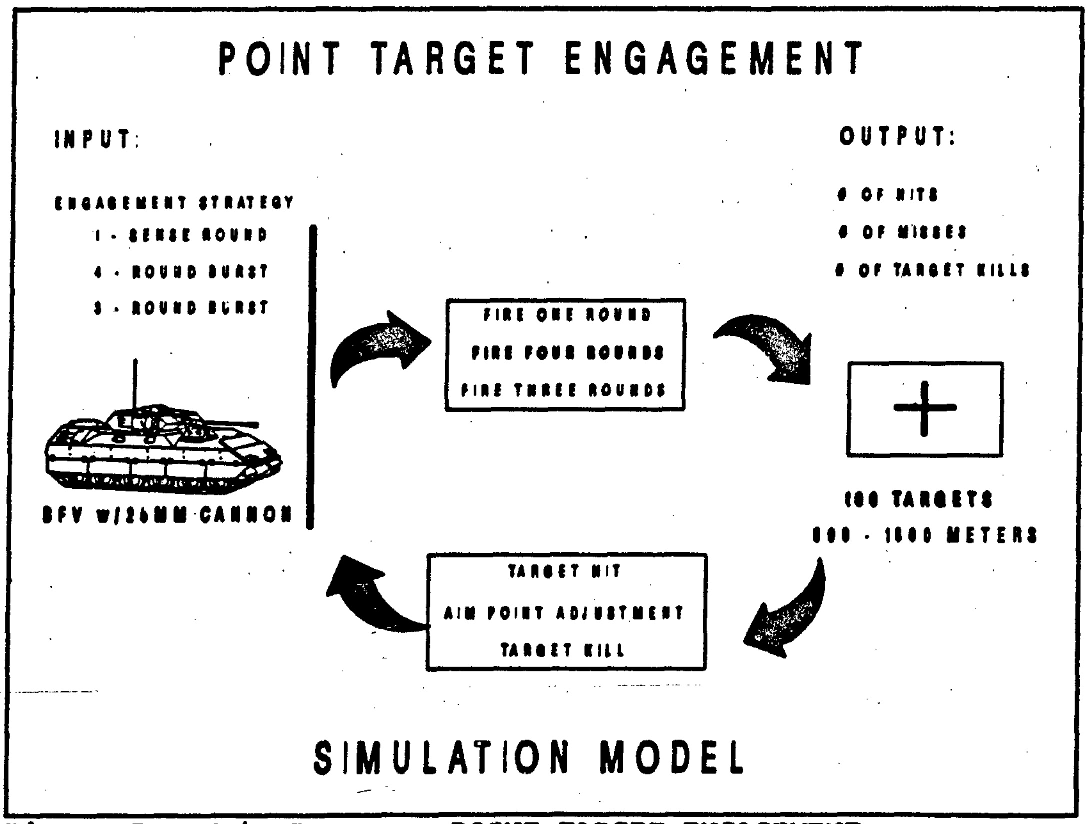


Figure 5. Main Program, POINT TARGET ENGAGEMENT

3.3.1 Main Program. As depicted, the simulation executes a designated engagement strategy, for instance {1 - 4 - 3}, against a BMP type target, of random visible size and range. The three phases of the strategy are executed

sequentially as they would by a live gunner/commander crew with the results of each round fired related back for appropriate corrective actions similar to actual BOT procedures. The simulation records total number of target hits and whether the target suffered a three round kill.

The firing processes are captured in three subroutines that represent a first sensing round or burst, a possible subsequent single sensing round, and multiple round 'killing' bursts.

3.3.2 Sensing Rounds and Bursts. An engagement begins with the gunner firing either a sensing round or a multiple round burst. Figure 6 depicts this process as represented by the simulation. The target has been detected and evaluated by the crew and the commander has made the decision to engage it with the 25mm. The commander gives his fire command while he and the gunner perform their individual preparatory actions. The model subroutines SENSE and FRSTBURST perform the crew actions as listed, simulate the ballistics of the round(s) and return the results to the main program.

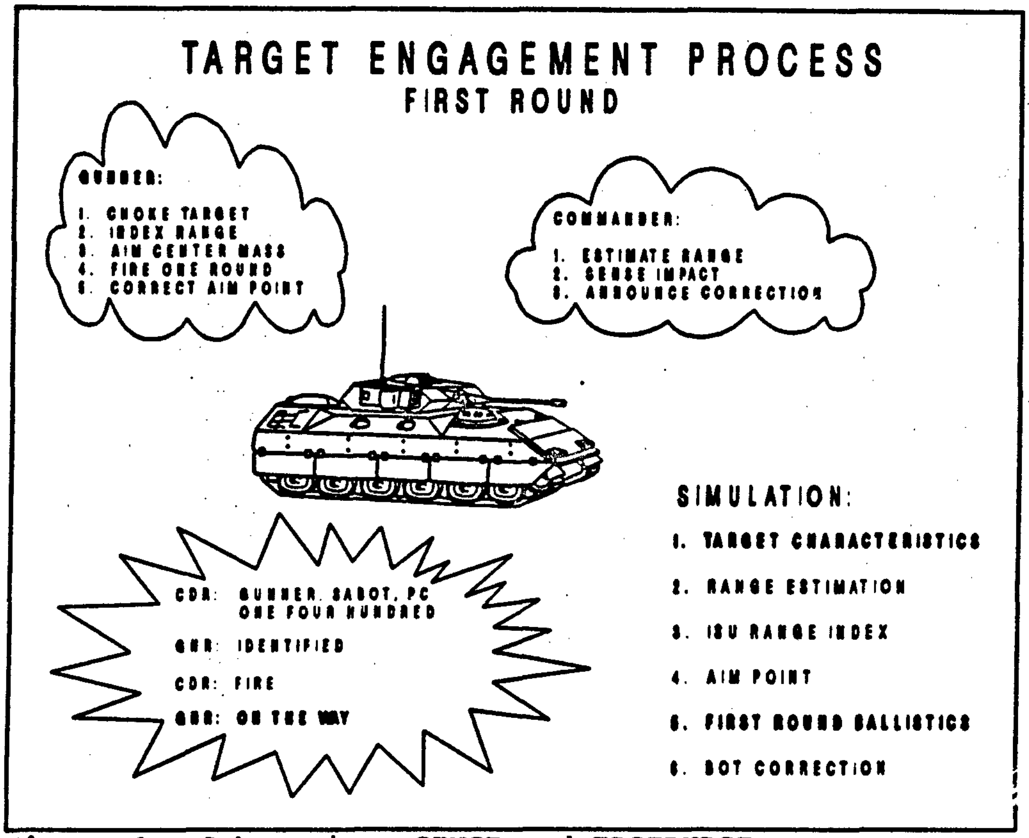


Figure 6. Subroutines SENSE and FRSTBURST

3.3.3 Range-in. An engagement strategy may include a second single sensing round to further improve the gunner's aim point prior to firing a 'kill' burst; the engagement strategy {1 - 1 - 3 - 3} for example. The gunner applies the aim point correction given by the commander and fires a single round. The BOT process is repeated based on the observed impact of the round. Figure 7 shows this continuation of the range-in process and its representation within the simulation.

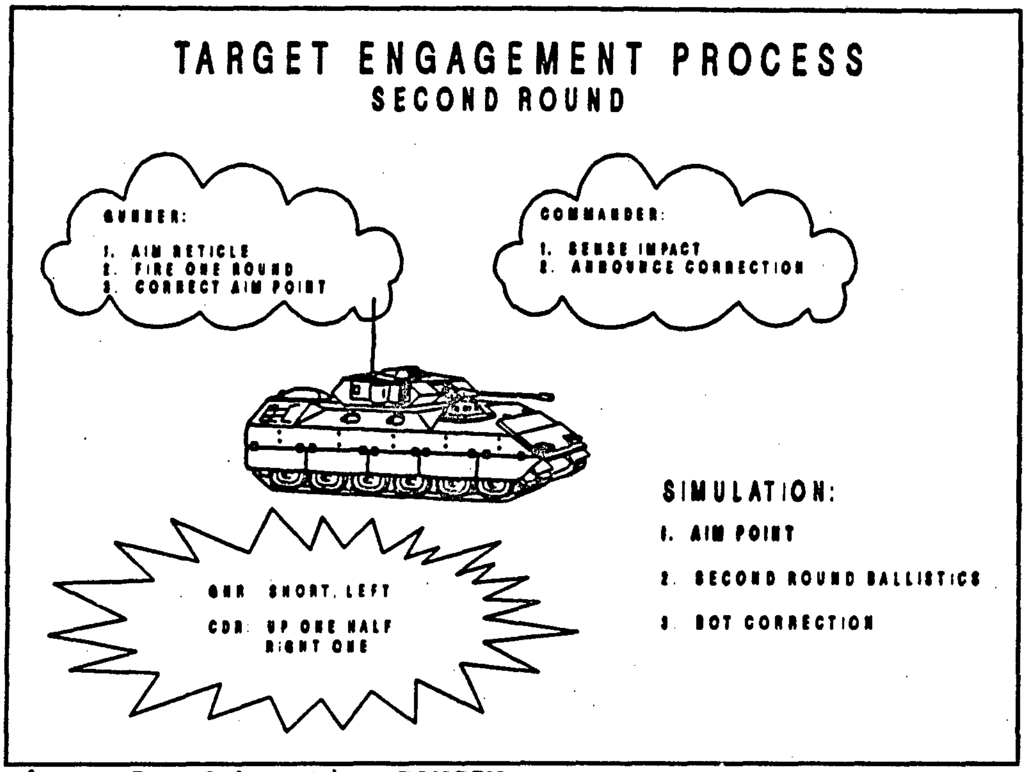


Figure 7. Subroutine RANGIN

3.3.4 Killing Bursts. After the range-in process is completed, the engagement strategy ends with one or a series of multiple round 'kill' bursts in order to inflict maximum damage on the target. The range-in process hopefully produced a target hit so that the ensuing burst(s) has a high probability of impacting on the target. Within the overall engagement process, the gunner or commander announces a target hit if observed and the commander continues to announce aim point corrections between bursts. When the target is destroyed (three rounds have impacted on the target) the commander terminates the engagement. Figure

8 represents this portion of the engagement and details the aspects captured by the simulation.

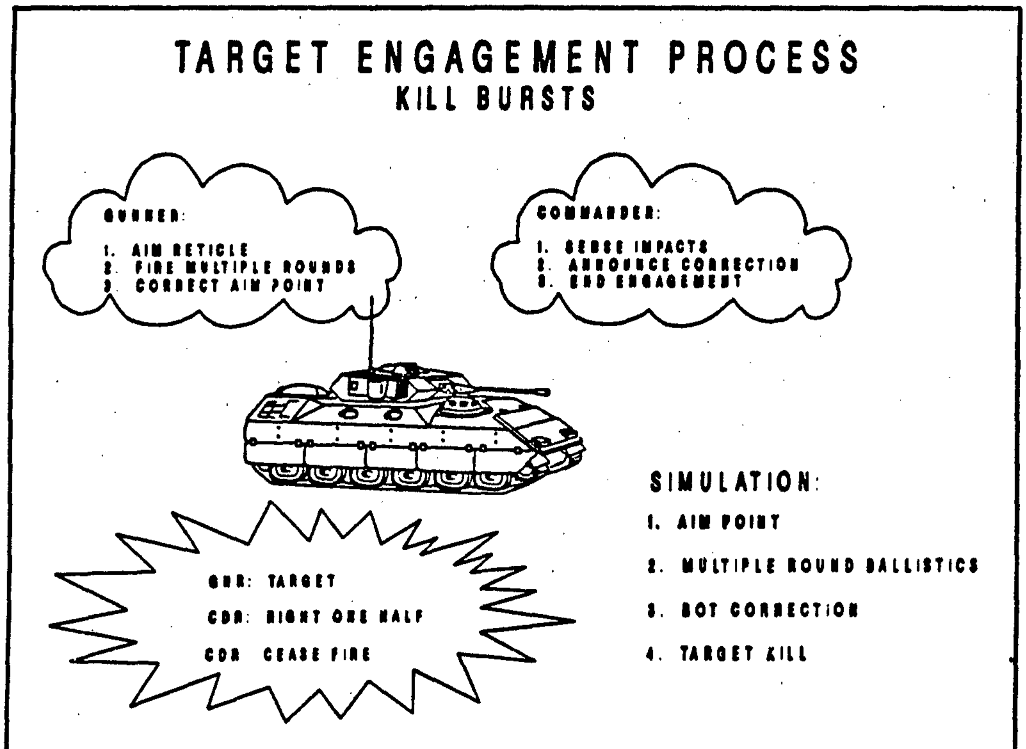


Figure 8. Subroutine KILLBURST

3.3.5 ***Fire for Effect.*** Three rounds impacting on an actual BMP will probably not result in a mobility or firepower kill. The actual estimated numbers are classified. To achieved the desired level of target destruction, the Bradley crew will continue to fire multiple round bursts. As roted, it is assumed these bursts will be equal in length. The EFFECTS subroutine uses the same processes as KILLBURST to represent this continuation of the initial eight round engagement strategy. In order to produce a common performance measure for the different

burst lengths, the simulation fires 60 rounds using each of the three, four, or five round burst patterns.

3.4 A Methodology for Estimating Quasi-Combat Dispersions for Automatic Weapons.

The tactical error of the M242 25-mm Hughes chain gun mounted in the Bradley Fighting Vehicle System (BFVS) firing the M791 APDS-T, and M792 HEI-T rounds will be defined by residual errors. The term residual error used throughout ... refers to the standard deviation about the adjusted centers of impact of many bursts over many replications. It includes all sources of error. This residual error includes primarily the effects of adjustment between bursts as well as the effects of ranging in.

3.4.1 Development Test (DT) Dispersions. The DT dispersion tests of the 25-mm M242 weapon were conducted at Aberdeen Proving Ground (APG) between April 1978 and June 1980. Both hard stand testing of the 25-mm weapon and ammunition, and entire weapon system testing from the BFVS were conducted. The hardstand estimates were based on both mann barrel and weapon firings which were combined after the statistical analysis indicated no significant differences. The vehicle testing was conducted under both stationary and moving firer conditions firing against both stationary and moving (crossing) targets. The weapon station has a stabilization system which allows a high degree of accuracy when firing on the move. The DT dispersion testing for the BFVS A1 vehicle was conducted in Oct-Dec 1984 and is the primary source for 25-mm dispersions.

These highly controlled tests were fired using expert civilian gunners from the Combat Systems Testing Activity (CSTA), formerly known as Material Testing Directorate (MTD) at APG. The weapon was zeroed at 1000 meters before each fired test condition. Time-to-fire was not an element of the test. The dispersions are representative of weapon-round repeatability performed under ideal test conditions, and are not necessarily a good representation of the dispersions which would be obtained in a combat situation. The DT dispersions are shown in Table 2. The burst fire dispersions are defined with the "shotgun" or "2 distribution" model which implies that each round in a burst is equally likely to hit the target. The within burst dispersions are the standard deviations about the coordinates of each round within a burst considering azimuth (AZ) and elevation (EL) independently. The burst-to-burst dispersions are the standard deviations about the centers of

impact of a group of bursts in the horizontal (AZ) and vertical (EL) directions. These DT dispersions, unlike the residual errors, are not reflective of most of the error budget components, the adjustments between bursts or the ranging-in process.

3.4.2 First Round Hit Probability. ... The Armored Warfare Analysis Branch's (AWAB) PH1 model is documented in the report *Tank Fire Control Error Budgets* (35). Basically, the model breaks down the delivery accuracy for the first round of a weapon system into many smaller components known as the 'error budget,' and calculates the first round hit probability for expected representative combat conditions. Included in the error budget is the round-to-round dispersion obtained during the DT tests. The PH1 has been used for years in AWAB to evaluate large caliber single shot weapons such as tank guns. ... the effectiveness of the first round of 25-mm APDS-T ammunition against a vehicle target was felt to be significant so the methodology was applied.

Table 2

25-mm DT Dispersion Estimates (mils) *

(2:9)

Weapon/Target Role	Horizontal	Vertical
	Single Shot Dispersions	
Stationary/Stationary	0.46	0.48
Stationary/Moving	0.54	0.49
Moving/Stationary	0.70	0.67
	Within Burst	
Stationary/Stationary	0.46	0.38
Stationary/Moving	0.49	0.50
Moving/Stationary	0.69	0.67
Moving/Moving	0.71	0.77
	Burst-to-Burst	
Stationary/Stationary	0.28	0.33
Stationary/Moving	0.50	0.26
Moving/Stationary	0.53	0.22
Moving/Moving	0.63	0.62

* Initial and contractor production vehicle/ammunition testing results data of Bradley Fighting Vehicle and DT

testing of BFVS A1. AP ammo fired at 100 rds/min in five round bursts ...

The PH1 combines the fixed horizontal and vertical biases of the weapon system with the total dispersions to produce a first round hit probability. The fixed biases are the summation of the effects due to parallax (the horizontal and vertical distances from the gunner's sight to the gun barrel), and horizontal drift of the round caused by spin of the projectile. For the APDS-T round, values for parallax and drift are 0 at (1200) meters since the gunner zeroes the weapon at that range. ...

The total horizontal (H) and vertical (V) dispersions are the root sum squared combinations of the random errors (H+V) and variable biases (H+V). The random errors are the root sum squared combinations of round-to-round dispersions (H+V) and quasi-combat lay errors (H+V). The round-to-round dispersions were taken from the stationary BFVS versus stationary target portion of the DT tests (Table 2). The quasi-combat lay error is attributed to the gunner's inability to lay the crosshair of a telescopic sight on the desired aimpoint in a stressed situation. The gunner gives up some precision for a savings in time-to-fire the first round. This error, which is based on a US time stress test and accepted by a NATO committee, has been used for many years and is valid for any weapon system using a similar telescopic sight.

There are many components which are root sum squared together to produce the variable biases (H+V). These components and the values used for the current BFVS fire control system are listed in Table 3. Descriptions of these components can be found in Shiflett's report (35). The largest sources of error are range estimation error, cant, and jump. The range estimation error is 17 percent of range for the BFVS fire control with its crude stadia range finder. This number is based on test data from similar tank studies. ... The 17 percent range estimation error is by far the largest source of error within the total error budget for ranges greater than 1000 meters. Cant error is the error in placing a weapon so that its elevation trunions are level resulting in and incorrect aim. The nominal value of five degrees is the largest source of error for the horizontal variable bias, especially at longer ranges. ... The occasion-to-occasion jump variable bias is caused by such things as tube vibration or angular rotation during projectile travel, projectile dynamic and aerodynamic unbalance, and tube bend from uneven heating of the barrel. Additional contributors to jump peculiar to the BFVS may be backlash, synchronization, removal and replacement of the weapons from the turret causing loss of boresight, and

Integrated Sight Unit (ISU) problems. This occasion-to-occasion jump may vary from occur in both horizontal and vertical directions. ... (2:7-13)

The results from PH1 provide the fixed horizontal/vertical biases and total horizontal/vertical dispersions of the 25-mm weapons system according to range and will be used in the simulation model to determine where the first round hits on the target plane.

Table 3

Input Values to PH1 for 25-mm APDS-T M791 Round Fired From M242 Gun Mounted on BFVS

Zeroed at: 1200 meters

(2:11)

H = Horizontal
V = Vertical

Fixed Biases (Meters)/Range (m)		0	1200
Parallax	H =	-0.6472	0
	V =	-0.4399	0
Drift	H =	0.0000	0.18

Random Errors

Round-to-Round Dispersion (H/V) = 0.46/0.48 mils (Stationary/Stationary)
Quasi-Combat Lay Error (H+V) = 0.3 meters + 0.05 mils

Variable Biases

Cant (H+V)	=	5.0	Degrees
Range Estimation Error (V)	=	17.0	Percent
Jump (H)	=	0.62	Mils
(V)	=	0.33	Mils
Crosswind (H)	=	11.0	Feet/ Second
Fire Control (H)	=	0.11	
(V)	=	0.2	Mils

Muzzle Velocity Variation (V)	=	23.4	Feet/ Second
Range Wind (V)	=	11.0	Feet/ Second
Air Temperature (V)	=	8.0	Deg F
Air Density (V)	=	1.5	Percent
Optical Path Bending (V)	=	0.03	Mils
Zeroing (Includes all below) (H+V			
Cant (H+V)	=	5.0	Degrees
Range Estimation Error (V)	=	17.0	Percent
Jump (H)	=	0.62	Mils
(V)	=	0.3	Mils
Crosswind (H)	=	11.0	Feet/ Second
Fire Control (H)	=	0.11	Mils
(V)	=	0.2	Mils
Muzzle Velocity Variation (V)	=	23.4	Feet/ Second
Range Wind (V)	=	11.0	Feet/ Second
Air Temperature (V)	=	8.0	Deg F
Air Density (V)	=	1.5	Percent
Optical Path Bending (V)	=	0.03	Mils
Group Center of Impact (GCI)(H+V)	=	0.21	Mils
Observation of GCI (H+V)	=	0.05	Mils

3.5 Point Target Engagement Simulation Model Documentation.

As previously defined, an engagement is a combination of single shots and/or multiple round bursts totaling eight, fired at a particular rate in order to destroy an identified target. The engagement strategy further distinguishes a specific pattern for these eight rounds. Point Target Engagement models this process. The simulation is structured to represent the various forms an engagement strategy might take. It is assumed, based on the ten second time standard established in *FM 23-1* for a single target engagement, that the shoot-look-shoot nature of Bradley

gunnery requires an engagement to be limited to four combinations of single and multiple round bursts. The SLAM based network provides the basic structure of the simulated engagement. An entity within the simulation represents a target. Each target is assigned an engagement strategy, range and width characteristics, and a set of statistical counters in the form of attributes. See Table 4. The target processes through four EVENT nodes which represent the specified combination of single and multiple round bursts fired and the accompanying adjustment of the reticle aim point based on BOT between bursts. After each burst is fired, the target is evaluated to determine if it has been killed. When the target has been completely engaged with eight rounds it continues to the COLCT nodes which count the number of target hits, misses, and kills. The simulation conducts 100 point target engagements. A flowchart of POINT TARGET ENGAGEMENT is shown in Figures A1 and A2, Appendix A.

Table 4

Target Attributes

ATRIB(1)	=	Number of rounds in first burst
ATRIB(2)	=	Number of rounds in second burst
ATRIB(3)	=	Number of rounds in third burst
ATRIB(4)	=	Number of rounds in fourth burst
ATRIB(5)	=	Mode: Battlesight of Precision
ATRIB(6)	=	Range to target
ATRIB(7)	=	Target aspect (width)
ATRIB(8)	=	Location of round/burst on horizontal axis
ATRIB(9)	=	Location of round/burst on vertical axis
ATRIB(10)	=	Number of target hits
ATRIB(11)	=	Number of target misses
ATRIB(12)	=	Target Kill (> 3 target hits)

3.5.1 Engagement Strategy. Five attributes distinguish an engagement strategy; attributes one through four specify the number of rounds the gun will fire in each of the four possible bursts and attribute five designates whether the target is engaged in precision or battlesight mode.

3.5.2 Target Characteristics. Attribute six assigns the target a range from a uniform distribution between 800 and 1800 meters using SLAM's internal random number generating capability. It is assumed that the majority of

engageable targets would present themselves uniformly between these two ranges without regard to the doctrinal planning factors of mission, enemy, troops, terrain, and time (METT-T) which would normally be expected to refine the range possibilities. Attribute seven assigns the target a width from a uniform distribution between 2.94 meters (full frontal) and 6.74 meters (full flank). This is a conservative representation of the full range of possible target aspects which will be used in an attempt to capture the non-rectangular nature of the BMP as a target, especially the area created by the 57 degree frontal slope.

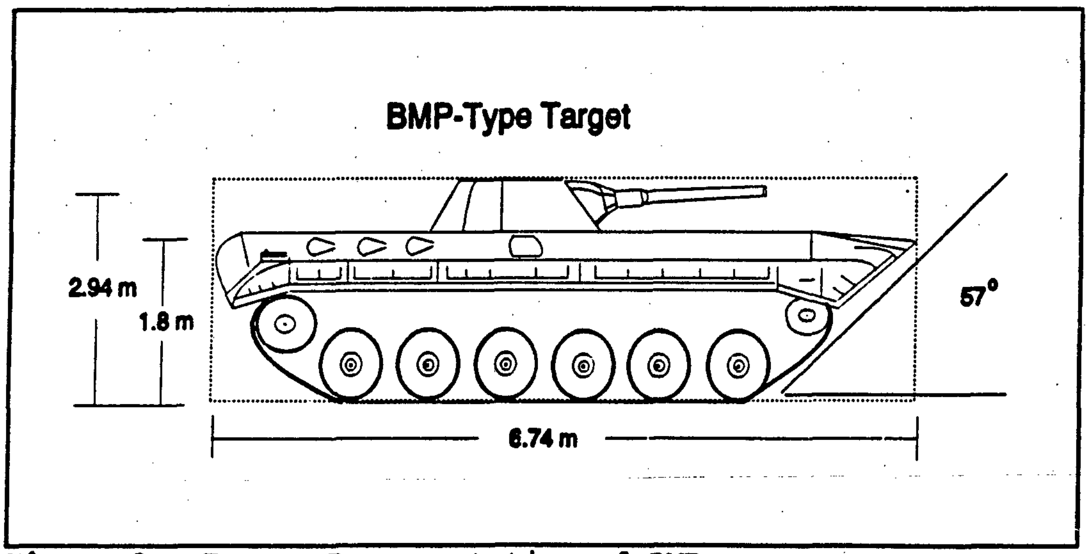


Figure 9. Target Representation of BMP

According to research conducted by Mike S. Perkins, of Litton Systems, Inc., "the visible total width of a BMP is larger between 45 and 90 degrees than it is at 90 degrees (24:4)." Table 5 lists the complete range of BMP total visible width as it corresponds to angular orientation to

the observer. Note that at 65 degrees the width of the BMP is actually 7.35 meters, however, the area near the frontal slope should not be considered as true target area. While not geometrically precise, the chosen representation limits the inflated hit probabilities which would result if the full range of target aspects were used.

Table 5

Visible Width (m) of a BMP Oriented at Varied Angles

(24:5)

Target angle (degrees)	Visible front width (m)	Visible side width (m)	Visible total width (m)
0	2.94	0.00	2.94
5	2.93	0.59	3.52
10	2.90	1.17	4.07
15	2.84	1.74	4.58
20	2.76	2.31	5.07
25	2.66	2.85	5.51
30	2.55	3.37	5.92
35	2.41	3.87	6.27
40	2.25	4.33	6.58
45	2.08	4.77	6.84
50	1.89	5.16	7.05
55	1.69	5.52	7.21
60	1.47	5.84	7.31
65	1.24	6.11	7.35

70	1.01	6.33	7.34
75	0.76	6.51	7.27
80	0.51	6.64	7.15
85	0.26	6.71	6.97
90	0.00	6.74	6.74

3.5.3 Statistical Counters. The simulation tracks the impact of each round or the center of each multiple round burst fired at the target using attributes eight and nine to represent the impact location on the horizontal and vertical axis respectively. Conditional ACTIVITIES following each return from subroutine EVENT records which burst fired actually killed the target. The number of target hits are collected from attribute ten, target misses from attribute eleven, and target kills from attribute twelve.

3.6 Subroutine Event

Subroutine Event controls the seven possible burst patterns that make up an engagement strategy:

1. No rounds are fired.
2. Single first round burst is fired.
3. Single second round burst is fired.
4. Multiple first round burst is fired.
5. Multiple second round burst is fired.
6. Multiple third round burst is fired.
7. Multiple fourth round burst is fired.

These seven patterns can be combined to capture all of the proposed engagement strategies. Based on the designated engagement strategy, Subroutine Event calls the appropriate FORTRAN subroutine to represent the type of burst fired and returns the results of that burst back to the main program. A flowchart of EVENT is shown in Figures A3 - A5.

3.7 Subroutine Sense

Subroutine SENSE, Figures A6 - A7, represents a first single sensing round fired at the target. The aimpoint is the center of the visible target defined by the standard BMP target height of 2.2 meters and the variable target width generated by the main program, Point Target Engagement. The muzzle of the gun is assumed to be at the same height as the center of the target. According to Herrmann, in *Exterior Ballistics 1935*, "in any practical case the angle of position is so small that no distinction need be made" between a gun located above/below the target center and one which is at the same height. (17:17) The subroutine is divided into five distinct steps:

1. Computation of First Round Fixed Biases and Total Dispersions.
2. Range Estimation and ISU Index Procedure.
3. Calculation of Vertical Miss Distance (VMD).
4. Calculation of the Impact Point of the Round.
5. Calculation of Aim Point Correction.

On completion of these steps, SENSE determines the number of target hits, target misses, and the new target aim point and returns this information to the main program.

3.7.1 Computation of Fixed Biases and Total Dispersions at Target Range. First round fixed biases (***FBH, FBV***) and total dispersions (***DISPH, DISPV***) from PH1 are used to determine where the first round impacts on the target plane. The results from PH1 for 100 meter increments between ranges of 200 and 2000 meters are found in Table 6.

Table 6

RESULTS FROM PH1
Fixed Biases and Total Dispersions (mils)
(31:1-2)

RANGE (M)	DISPH	DISPV	FBH	FBV
400	1.2121	1.1081	-1.6926	-1.1202
500	1.1190	1.0137	-0.8045	-0.5228
600	1.0670	0.9673	-0.5800	-0.3734
700	1.0369	0.9485	-0.4182	-0.2667
800	1.0198	0.9477	-0.2955	-0.1867
900	1.0112	0.9596	-0.1989	-0.1245
1000	1.0084	0.9815	-0.1205	-0.0747
1100	1.0100	1.0113	-0.0553	-0.0339
1200	1.0150	1.0479	0.0000	0.0000
1300	1.0229	1.0906	0.0477	0.0287
1400	1.0332	1.1389	0.0895	0.0533
1500	1.0456	1.1922	0.1266	0.0747
1600	1.0601	1.2505	0.1599	0.0933
1700	1.0764	1.3135	0.1901	0.1098
1800	1.0945	1.3810	0.2178	0.1245
1900	1.1142	1.4531	0.2433	0.1376
2000	1.1356	1.5297	0.2670	0.1494

Within the subroutine, a linear regression model for each of these dependent error variables is used to estimate the biases and dispersions at the appropriate target range. Computation of the regression models are covered in Appendix

C, however, their R-squared values are .9738, .9703, .8715, and .9880 respectively.

$$FBH = -1.7834 + .00227RG - 6.453E\text{-}07RG^2 \qquad (21)$$

$$FBV = -1.17336 + .00152RG - 4.424E\text{-}07RG^2 \qquad (22)$$

$$DISPH = 1.31464 - 4.955E\text{-}04RG + 2.033E\text{-}07RG^2 \qquad (23)$$

$$DISPV = 1.20873 - 5.813E\text{-}04 + 3.712E\text{-}07RG^2 \qquad (24)$$

3.7.2 Range Estimation and ISU Range Index. The engagement can be fired in either the precision or battlesight mode. Range estimation is inherent to both of these firing modes. As previously noted, *FM 23-1* identifies two battlesight indexes; 1200 for targets within 1400 meters and 1600 for targets exceeding 1400 meters. It further recommends a quick range estimation procedure using the horizontal lead lines to determine when the target lies within or outside the critical 1400 meter range. (5:3_19-3_20, 3_28-3_29) It is assumed that the average gunner can adequately use this method to determine the correct battlesight range index. The AMSAA standard 17% range estimation error will therefore be applied to precision and battlesight engagements since the stadia sight is used in both methods for range estimation (2:6,10; 18). Given RN3 is a normally distributed random number and the Percent

Range Error (PRE) equals 17 percent, the estimated range is defined as:

$$RGEST = RANGE \cdot PRE \cdot RN3 + RANGE \tag{25}$$

The ISU index range in the precision mode is the closest 200 meter increment to the estimated range. Based on conversations with Master Gunners from the Bradley Gunnery offices at both Fort Benning and Fort Knox, as well as the authors personal experience, it is assumed that most gunners would rather index low so their first round, if it misses, will impact in the dirt. This creates a more definite signature on which to base their BOT correction (13). Precision mode index range (INDEX) is defined as:

$$INDEX = 2(AINT(RGEST/200)) \tag{26}$$

The FORTRAN intrinsic function *AINT(al)* is used to represent the assumption that the gunner would index the next lowest range from his estimate.

3.7.3 Calculation of Vertical Miss Distance on the Target Plane. Targets will very rarely present themselves at ranges which correspond exactly to the index settings available to the ISU. Therefore, even if the effects of fixed biases and variable dispersions were ignored, most first rounds would fail to hit the gunner's aim point. To evaluate whether a particular round impacted on the visible target plane, the vertical miss distance from the target

center must be estimated. In his book, *Exterior Ballistics 1935*, Herrmann presents a method for determining this distance for short ranges using a projectile's angle of fall. "The angle of fall is the angle between the horizontal plane (horizontal line from the gun to the point of aim) and the tangent to the trajectory at the point of fall" (17:6-7). See Figure 10.

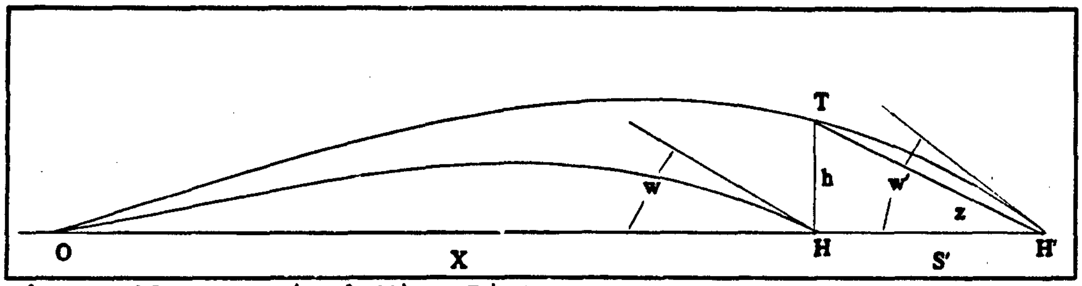


Figure 10. Vertical Miss Distance

In Figure 10 the 25-mm gun is located at *O* and a BMP type target is located at range *OH* = *X*. The aim point is assumed to be at *H*; the center of target visible mass. The trajectory *OH*, representing the gun shooting at a target at the exact index range, has a point of fall at *H* and angle of fall *w*. The trajectory *OH'*, represents the gun shooting with an index range greater than the true range to the target. The point of fall for this trajectory is *H'* and the angle of fall is *w'*. *T* represents the point where the round crosses the vertical plane of the target. The value of *h* is given exactly by the relation $h = S' \tan z$, in which *z* is the angle *TH'H*. This angle is unknown, but it appears that

w is approximately equal to ***z***, and that ***h*** can be defined by the relation:

$$h = S' \tan(w) \tag{27}$$

in which **w** is the angle of fall corresponding to the true target range. Herrmann states: "Although no rigorous proof of equality between the angles **w** and ***z*** is available, it has been established by exhaustive comparative solutions that these angles are indeed very nearly equal in any practical situation." (17:270) Equation (27) will be used within the simulation to determine vertical miss distance VMD (18; 17:268-270). Angle of fall values for 25-mm APDS-T ammunition comes from Ballistics Research Laboratory data dated November 1983 (1:1-2).

3.7.4 Computation of Impact Point. SENSE now determines where the round hits on the target plane. The aim point (***XAIM,YAIM***) is the center of the predefined rectangular target. For the first round only the first round fixed biases and total dispersions derived from PH1 along with the vertical miss distance are used to determine the impact point. Letting ***RN1*** and ***RN2*** be normally distributed random numbers (***N(0,1)***), the equations used to determine the impact coordinates (***XA,YA***) for the first round are:

$$XA = XAIM + FBHOR + RN1 \cdot DH \tag{28}$$

$$YA = YAIM + VMD + FBVEP + RN2 \cdot DV \quad (29)$$

where

VMD = Vertical Miss Distance
$FBHOR$ = Fixed Biases Horizontal
$FBVER$ = Fixed Biases Vertical
DH = Total Dispersions Horizontal
DV = Total Dispersions Vertical

The *X* and *Y* miss distances become:

$$XMISSD = XA - XAIM \quad (30)$$

$$YMISSD = YA - YAIM \quad (31)$$

The subroutine evaluates these miss distances against the target critical area to determine if a hit has occurred. The target critical area (*XLIM,YLIM*)is defined by the relations:

$$XLIM = TGTW/2 \quad (32)$$

$$YLIM = TGTH/2 \quad (33)$$

where

$TGTW$ = Target width

$TGTH$ = Target height

The number of hits (*NHITS*) and misses (*NMISS*) are recorded.

3.7.5 Burst on Target (BOT) Adjustment Process. As previously defined BOT is a direct fire adjustment technique in which the gunner and vehicle commander observe where the round strikes in relation to the target and convert the relationship into an executable correction for the original

point of aim. The currently accepted method for modeling this process is based on data obtained from the YAKIMA firing test conducted in support of the Infantry Warfare Analysis Branch's (IWAB) BUSHMASTER study. However,

> only the 20mm M139 gun mounted on an XM701 having GE (Weapons Contractor: General Electric) stabilization was fired at YAKIMA. The data provided is considered to be 'ball park' for the 20-30mm MICV (Mechanized Infantry Combat Vehicle) systems, but obviously cannot be guaranteed to be applicable to the current BFVS. The maximum range utilized in the test was 1800 meters. Extrapolation beyond 2000 meters may be risky. (2:18)

While further analysis is warranted to verify its representation of the actual BOT correction distribution, the YAKIMA method will be used throughout this simulation model. The YAKIMA data quantifies the correction of miss distances in terms of mean percent correction and standard deviation. The final mean correction was 0.4 of the miss distance with a standard deviation of 0.7. The correction algorithm is defined as:

$$XA = (0.4 + 0.7\,RN1)\,XMISSD + XAIM \tag{34}$$

$$YA = (0.4 + 0.7\,RN2)\,YMISSD + YAIM \tag{35}$$

where ***XA*** and ***YA*** represent the coordinates of the next round impact point. A flowchart of SENSE is shown in Figures A6 - A7.

3.8 Subroutine RANGEIN

Subroutine RANGEIN represents the firing of a second single sensing round at the target. It uses the new impact

point generated by subroutine SENSE and incorporates the weapon system's round-to-round dispersion factors to compute the second round impact point. RANGEIN uses the DT test round-to-round dispersions to determine the weapon system delivery error for the second round. Using random numbers ***RN1*** and ***RN2***, the round-to-round delivery errors are defined by the equations:

$$SDXERR = RN1 \cdot SDXZZ \qquad \textbf{(36)}$$

$$SDYERR = RN2 \cdot SDYZZ \qquad \textbf{(37)}$$

The delivery errors are used to compute the impact coordinates of the round based on the aim point (***XA,YA***) from SENSE:

$$XA = XA + SDXERR \qquad \textbf{(38)}$$

$$YA = YA + SDYERR \qquad \textbf{(39)}$$

The subroutine determines whether the round hit or misses the target and applies the YAKIMA adjustment method using the previously defined algorithms; Equations (34) and (35). The number of target hits, target misses and new target impact point are returned to the main program. A flowchart of RANGEIN is shown in Figure A9.

3.9 Subroutine FRSTBURST

Subroutine FRSTBURST represents the firing of a multiple round burst without a prior sensing round. It uses

the same procedural steps as subroutine SENSE, but incorporates the burst-to-burst and within-burst dispersions of the weapon system into the calculation of the individual round impact points. The DT test values for these dispersions are used. As noted in the description of the DT test, the within-burst dispersions are defined by the 'shotgun' model which implies that each round within the burst has an equal probability of hitting the target. An analysis of individual round impact data obtained during live-fire testing conducted by Ground Warfare Division, AMSAA confirmed that there is no significant auto-correlation or systematic dependence between rounds. (13) The results of this analysis are included in Appendix D.

Modeling a multiple round burst requires that two of the processes defined in SENSE be modified: computation of impact points and aim point adjustment.

3.9.1 Computation of Multiple Round Impact Points. Subroutine FRSTBURST must compute and evaluate the impact point of each round fired in the burst to determine if it hit the target. Since these are the first rounds fired at the target, the first round fixed biases and total dispersions derived from PH1 along with the vertical miss distance are used to determine the impact points using the same equations (28) and (29) defined in SENSE . FRSTBURST uses the DT test round-to-round and the within-burst dispersions to determine the weapon system delivery errors

for each round. Using random numbers ***RN1*** and ***RN2***, the round-to-round and within-burst delivery errors are defined as:

$$SDXERR = RN1 \cdot SDXZZ \tag{40}$$

$$SDYERR = RN2 \cdot SDXZZ \tag{41}$$

$$SCXERR = RN1 \cdot SCXSS \tag{42}$$

$$SCYEER = RN2 \cdot SCYSS \tag{43}$$

The delivery errors are used to compute the impact coordinates of the individual rounds by adding them to the impact points ***XA*** and ***YA*** determined with equations (28) and (29):

$$XAFER = XA + SDXERR + SCXERR \tag{44}$$

$$YAFER = YA + SDYERR + SCYERR \tag{45}$$

The subroutine determines whether each round hit or misses the target and accumulates the totals to return to the main program.

3.9.2 Burst on Target (BOT) Adjustment Process. FRSTBURST uses the YAKIMA adjustment algorithm, however, the adjustment is applied to the burst center of impact. It is assumed that gunners and Bradley commanders would evaluate the location of the combined burst impacts as opposed to identifying a single round, first or last round perhaps, on which to base their BOT correction. The burst center of

impact is defined as the mean impact coordinates for the number of rounds in the burst:

$$XA = SMX/NRBS \tag{46}$$

$$YA = SMY/NRBS \tag{47}$$

where

NRBS = Number of rounds in the burst
SMX = Sum of horizontal axis impact coordinates
SMY = Sum of vertical axis impact coordinates

The YAKIMA adjustment algorithm is applied the center of impact using equations (34) and (35) defined above. A flowchart of FRSTBURST is shown in Figures A10 - A12.

3.10 Subroutine KILLBURST

Subroutine KILLBURST represents the multiple round burst(s) a gunner uses to kill the target. The range in process has technically ended, although it is assumed that the gunner and Bradley commander will continue to use BOT to fine tune the round impacts on the target. KILLBURST uses the same methodology as subroutine SENSE, but incorporates the burst-to-burst and within-burst dispersions of the weapon system into the calculation of the individual round impact points. The DT test values for these dispersions are used and applied in the same manner as in subroutine FRSTBURST. The BOT adjustment process is modeled using the YAKIMA algorithm as defined by equations (46), (47), (34) and (35) in FRSTBURST. The resulting accumulated target

hits, target misses and adjusted aim point coordinates are then returned to the main program. A flowchart of KILLBURST is shown in Figures A13 - A14.

3.11 Subroutine EFFECTS

Subroutine EFFECTS uses the same procedures as KILLBURST. A DO-loop is added to allow the firing of a designated number of multiple round bursts.

3.12 Validation and Verification

As noted earlier, POINT TARGET ENGAGEMENT uses virtually the same structure and algorithms as AMSAA's HITPROB2 model to represent the Bradley 25-mm gun system. Whereas HITPROB2 is a replications model, the simulation in this research is designed to model single discrete engagements. Delivery error parameters within the simulation are based on accredited AMSAA data from their PH1 model. The vertical miss distance algorithm was modified slightly because the AMSAA version could not be documented. The resulting calculations, documented from Herrmann (17), will probably provide a more conservative estimate.

The SLAM based shell of the model allowed for a logical and systematic verification process. Using a single target replication, several engagements were created round by round to test the shoot-look-adjust-shoot representation of the

gunnery process. This iterative approach confirmed the following:

a. Target range and aspect changed with each new engagement.

b. Firing mode selection occurred and resulted in different first round impact points.

c. Single and multiple round burst locations were recorded.

d. The aim point correction process resulted in improved impact points for subsequent rounds.

e. The statistical counters functioned properly.

Complete validation of the simulation is impossible, however, the outputs appear to be credible and consistent with AMSAA's results in other but related Bradley studies (2:16,36; 18; 29).

IV. *Methodology*

4.1 Introduction

This chapter discusses the methodology that will be used to answer the research questions: 1. What is the best engagement strategy for the BFV 25-mm firing APDS-T ammunition at a BMP type point target? 2. What is the most efficient burst size for expanding the initial engagement strategy to achieve the desired target effect? An outline of the proposed research process is presented followed by a description of the experimental design used to analyze the model outputs. The selected measures of effectiveness (MOE) will be discussed along with a theoretical description of the output analysis techniques to be used in determining relative performance.

4.2 Research Procedure

The research effort began with a literature review of weapon system modeling, summarized in Chapter 2, to identify techniques appropriate for representing the Bradley's 25-mm gun. The AMSAA model HITPROB2 provided the basic structure for a simulation designed to answer the specific research questions. AMSAA was reviewing two aspects of this model, the Aim and Aimpoint Adjustment (AAA) algorithm and ballistic dispersion parameters, which would impact similar portions of the research specific simulation.

They conducted live-fire testing using M791 ammunition during the period 12-16 September 1992, the results of which were included as appropriate (12:1,6; 13).

Since there are numerous engagement strategies possible and known to be in use throughout the Army, a letter requesting input from the Bradley community was submitted to the January-February 1993 issue of *INFANTRY* magazine. The responses from this inquiry will be added to the strategies known from the author's personal experience and evaluated using the simulation model.

The results were evaluated using the statistical procedures outlined below.

4.3 Experimental Design

The model, POINT TARGET ENGAGEMENT, simulates the Bradley gunnery process. It provides output data, which represents quantitative measures of 25-mm gunnery performance, in the form of a probability distribution of accumulated target hits or alternatively total targets killed. The random variation inherent in Bradley gunnery performance is influenced by a number of factors, some which can be controlled and some that cannot. See Figure 11.

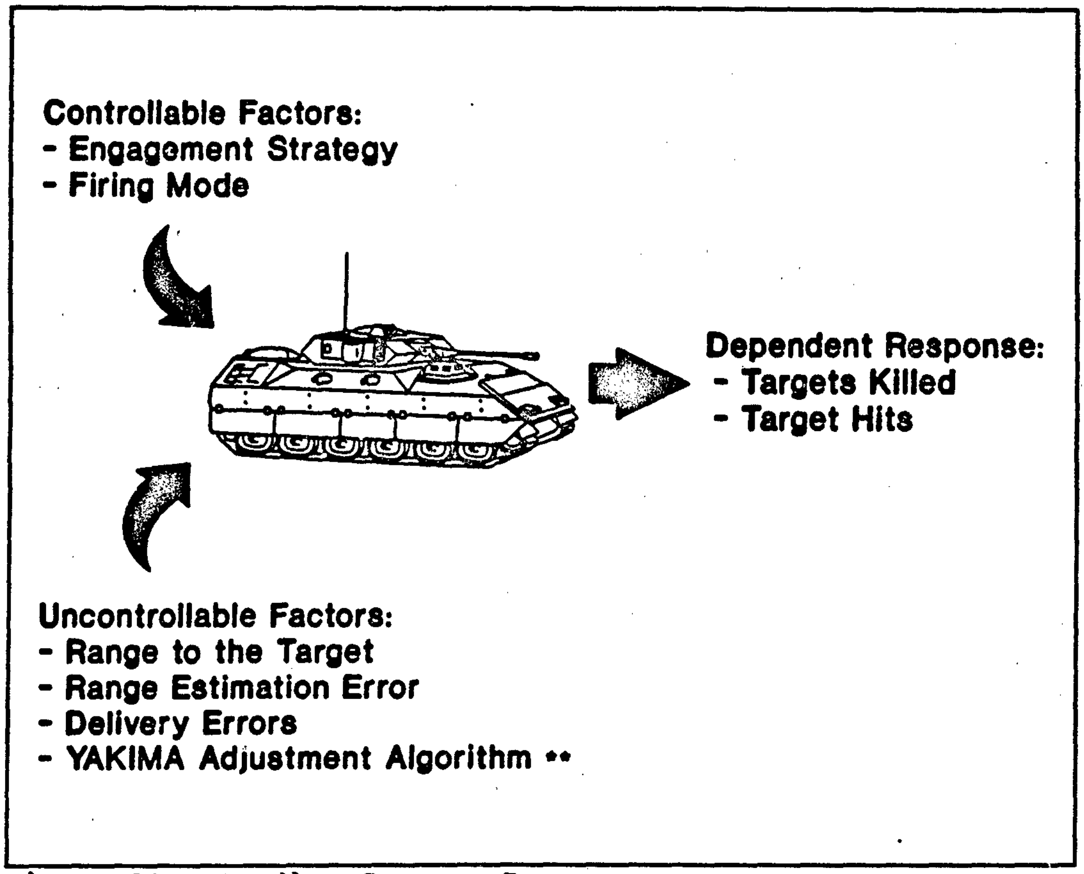


Figure 11. Bradley Gunnery Process

Each of the input factors influences the performance of the gunnery process to some degree. Of the controllable factors depicted, the engagement strategy used during a single BMP-type target engagement is the focus of the two research questions. We would like to determine if the influence or effect of using a particular engagement strategy significantly improves gunnery performance or if some engagement strategies are significantly better than others. Figure 12 shows the type of relationship we hope to capture.

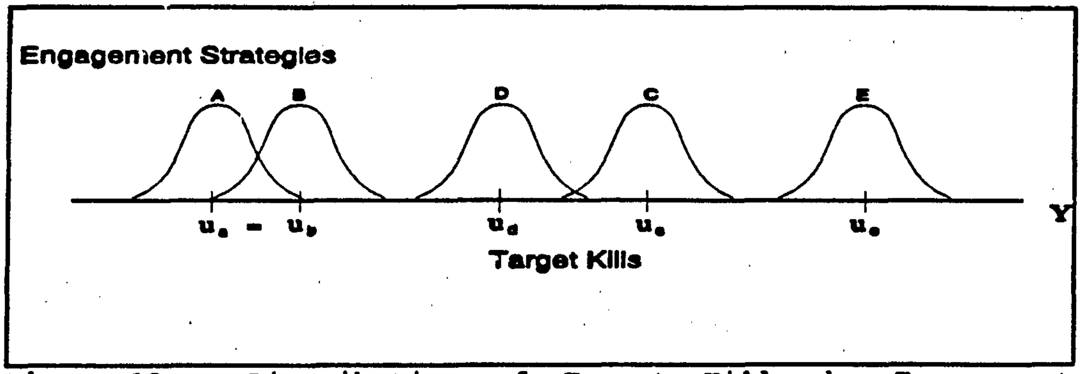


Figure 12. Distribution of Target Kills by Engagement Strategy

However, because firing mode, precision/battlesight, is also a controllable aspect of gunnery, we must also determine its significance and whether an interactive relationship exists between engagement strategy and firing mode. It is assumed that gunnery performance in precision mode will be better than in battlesight mode. The additional accuracy in estimating the location of the target found in precision mode procedures should result in a higher level of target hits/kills regardless of the engagement strategy used. However, if an interactive relationship exists between firing mode and engagement strategy, the anticipated improvement between firing modes would change depending on the engagement strategy used. Figure 13 graphically shows the two possible situations.

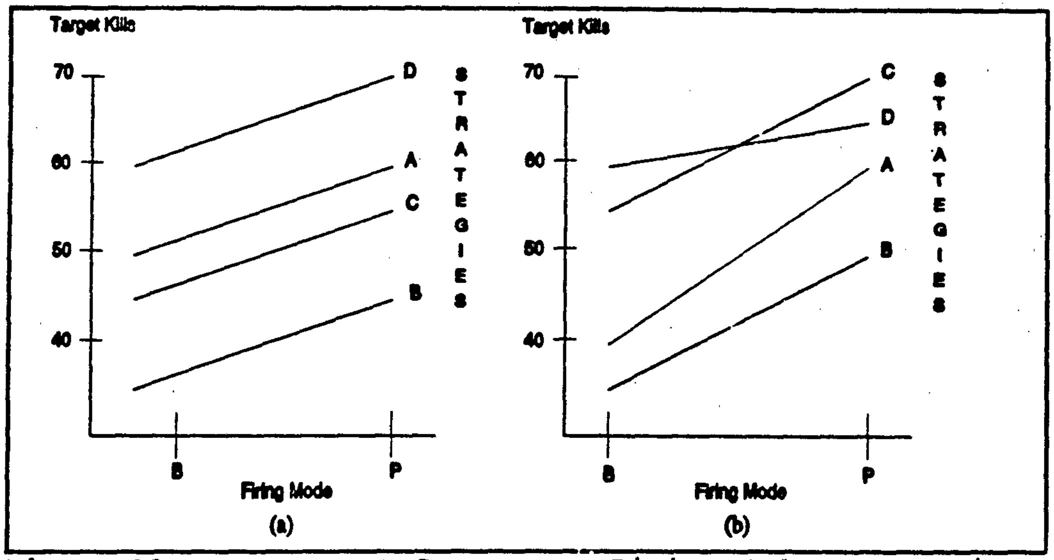


Figure 13. Engagement Strategy - Firing Mode Interaction

In Figure 13a, there is no interaction present. Target kills increase uniformly as the firing mode changes from battlesight to precision mode. In Figure 13b, interaction is present. Target kills still increase as the firing mode changes, but the increases differ according to the engagement strategy used.

The YAKIMA Aim Point Adjustment Algorithm, although considered an uncontrollable factor in that it models relative human performance, is also a point of concern for this research. It has been identified as the weak link in AMSAA's HITPROB2 model and therefore must be considered a question mark in the validity of POINT TARGET ENGAGEMENT as well. (29:3; 2:18) An additional research question is therefore: If the YAKIMA method is wrong, how does a change to the algorithm influence the interpretation of the model's results? For the purpose of experimentation, this factor

can be fixed at various levels in order to test the significance of the YAKIMA algorithm as a contributing factor and whether it will interact with the engagement strategy factor as well. A strong interaction would indicate that our results must be interpreted based on an assumption that the YAKIMA algorithm is correct. Refer to Figure 14.

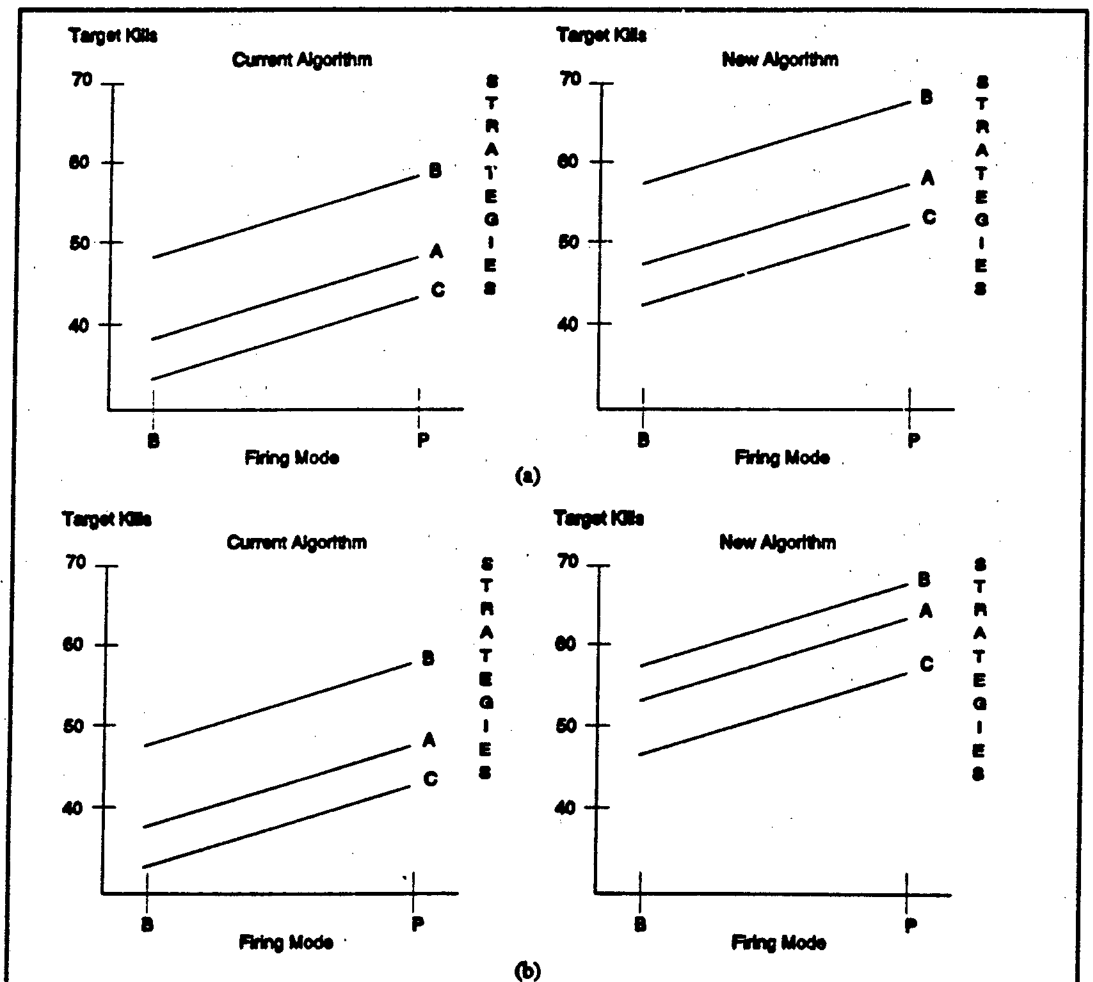


Figure 14. Interpretation of Engagement Strategy - YAKIMA Algorithm Interaction

Figure 14a shows the potential effect of the YAKIMA algorithm as a significant factor without interaction. The change to the algorithm produces a uniform improvement for each of the engagement strategies. The model, under these conditions, would be considered sensitive to the algorithm assumption, however, the relative performance of the engagement strategies would remain consistent for all forms of the aim point adjustment algorithm. Figure 14b shows how the presence of a strong interaction between the YAKIMA algorithm assumption and engagement strategy would complicate and confuse the analysis. The amount of improvement depends on both the change in the algorithm and the particular engagement strategy.

These three factors, engagement strategy, firing mode, and aim point adjustment algorithm, will be used to quantify or explain a portion of the total variance within modeled gunnery performance. The remaining factors depicted in Figure 11, range to the targets, range estimation error, and weapons delivery errors, are assumed to be uncontrollable and remain sources of unexplained variance in the gunnery process.

The various statistical tests conducted to answer these research questions are applications of analysis of variance methods. Analysis of variance (ANOVA) models are statistical tools for studying the relation between one or more independent variables and a dependent response

variable. ANOVA methods allow us to characterize the various sources of variance in the Bradley gunnery process and determine how a single factor or combination of factors influence relative performance. A multifactor study, in which the effects of two or more factors are investigated simultaneously, is used to answer the first research question and to perform the sensitivity analysis on the YAKIMA algorithm assumption. The second research question is addressed using a single factor study. The designs for these experiments follow.

4.3.1 Research question #1: What is the best engagement strategy for the BFV 25-mm firing APDS-T ammunition at a BMP-type point target?

As discussed above, in order to answer this question we must determine if any interactions exist that will complicate the analysis of how the various engagement strategies effect performance. For this reason, tests for two and three factor interactions are conducted first. The goal is to isolate the engagement strategy factor and determine whether one particular strategy or a group of strategies will maximize the mean number of target kills.

4.3.1.1 The model. Target kills will be the dependent variable. As defined in FM 23-1, success for a BMP-type single target engagement in Bradley gunnery is the 3-round 'kill' (5:11_5). Additional rounds impacting on the target, while certainly relevant in an actual combat duel

with a BMP, have no real meaning in the training environment. This aspect of the initial eight-round engagement strategy will not be evaluated.

The independent variables or factors are engagement strategy, firing mode, and aim point adjustment algorithm. The following seven engagement strategies will be evaluated as levels of the main factor:

A.	1 - 1 - 1 - 5	E.	1 - 2 - 5
B.	1 - 1 - 2 - 4	F.	1 - 3 - 4
C.	1 - 1 - 3 - 3	G.	2 - 3 - 3
D.	1 - 2 - 2 - 3		

The strategy (1 - 4 - 3) was dropped from the model because it proved to be statistically equal to (1 - 3 - 4) using target kills as an MOE.

There are 35 possible combinations of eight rounds under the assumption that no more than four shoot-look-adjust-shoot procedures were feasible within the ten second time constraint for a single target engagement specified in FM 23-1 (5:11_29). These seven strategies were selected from those possible based on the author's gunnery experiences as the commander of a Bradley equipped infantry company and conversations with Master Gunners from Fort Knox, Kentucky and the Bradley Proponency Office at Fort Benning, Georgia (13). This list may not include every strategy currently in use throughout the Army, but merely the most common as they could be determined by the author.

The second factor, firing mode, will be categorized at two levels according to either precision (P) or battlesight (B) engagement procedures.

The third independent factor represents the YAKIMA aim point adjustment algorithm. The factor will be tested at three levels reflecting the algorithm as it currently appears in POINT TARGET ENGAGEMENT and the algorithm with a higher and lower mean correction value. The assumption is that the YAKIMA algorithm either over- or underestimates the average Bradley crew's ability to apply BOT adjustment procedures. The resulting test levels for the algorithm are:

$$L \rightarrow \begin{aligned} XA &= (0.7+0.7RN1)\,XMISSD + XAIM \\ YA &= (0.7+0.7RN1)\,YMISSD + YAIM \end{aligned} \tag{48}$$

$$M \rightarrow \begin{aligned} XA &= (0.4+0.7RN1)\,XMISSD + XAIM \\ YA &= (0.4+0.7RN1)\,YMISSD + YAIM \end{aligned} \tag{49}$$

$$H \rightarrow \begin{aligned} XA &= (0.2+0.7RN1)\,XMISSD+XAIM \\ YA &= (O.2+0.7RN2)\,YMISSD+YAIM \end{aligned} \tag{50}$$

The remaining factors which influence gunnery performance; range to the target, range estimation error, and weapon system delivery errors are assumed to be captured in the error term.

The linear statistical model is therefore:

$$Y_{ijk} = \mu+\tau_i+\beta_j+\gamma_k+(\tau\beta)_{ij}+(\tau\gamma)_{ik}+(\beta\gamma)_{jk}+(\tau\beta\gamma)_{ijk}+\epsilon_{ijkl} \tag{51}$$

where the factor effects are defined by

$$
\begin{aligned}
\tau_i &= \textit{engagement strategy } A \ldots G \\
\beta_j &= \textit{firing mode } P \textit{ or } B \\
\gamma_k &= \textit{algorithm } L\text{ , } M \textit{ or } H \\
(\tau\beta)_{ij} &= \textit{strategy/mode interaction} \\
(\tau\gamma)_{ik} &= \textit{strategy/algorithm interaction} \\
(\beta\gamma)_{jk} &= \textit{mode/algorithm interaction} \\
(\tau\beta\gamma)_{ijk} &= \textit{strategy/mode/algorithm interaction} \\
e_{ijkl} &= \textit{random error for all } l \textit{ replications}
\end{aligned}
$$

4.3.1.2 The hypotheses tests. Seven tests are possible using the three-factor model, however, only six are of particular interest.

1. Do engagement strategy and algorithm interact?

$$
\begin{aligned}
&H_o:\ (\tau\gamma)_{ik} = 0 \quad \textit{for all } i,k \\
&H_a:\ \textit{at least one } (\tau\gamma)_{ik} \neq 0
\end{aligned}
\tag{52}
$$

2. Do firing mode and algorithm interact?

$$
\begin{aligned}
&H_o:\ (\beta\gamma)_{jk} = 0 \quad \textit{for all } j,k \\
&H_a:\ \textit{at least one } (\beta\gamma)_{jk} \neq 0
\end{aligned}
\tag{53}
$$

3. Do engagement strategy and firing mode interact?

$$
\begin{aligned}
&H_o:\ (\tau\beta)_{ij} = 0 \quad \textit{for all } i,j \\
&H_a:\ \textit{at least one } (\tau\beta)_{ij} \neq 0
\end{aligned}
\tag{54}
$$

4. Are the effects of the algorithms significant?

$$
\begin{aligned}
&H_o:\ \gamma_H = \gamma_L = 0 \\
&H_a:\ \textit{at least one } \gamma_k \neq 0
\end{aligned}
\tag{55}
$$

5. Is there a difference between firing in precision and battlesight mode?

$$
\begin{aligned}
&H_o:\ \beta_P = \beta_B = 0 \\
&H_a:\ \textit{at least one } \beta_j \neq 0
\end{aligned}
\tag{56}
$$

6. Are the engagement strategies different?

$$H_o: \tau_a = \tau_b = \cdots = \tau_g = 0$$
$$H_a: \text{ at least one } \tau_i \neq 0 \qquad (57)$$

4.3.1.3 Level of significance and sample size. Sample size for the experiment was determined using the power approach as outlined by Neter, Wasserman, and Kutner in *Applied Linear Statistical Models* (21:846). A single simulation run results in the number of targets killed out of 100 possible. There are 42 treatment combinations based on seven engagement strategies, two firing modes, and 3 levels of the algorithm factor. In order to detect a one standard deviation difference in the main effects, while limiting the risk of making a TYPE I error to .05 and a TYPE II error to .30, 144 replications for each of these treatment combinations are appropriate.

4.3.1.4 The test statistics. The total sums of squares for this model can be decomposed into the sums of squares for each factor, two-way interaction, three way interaction and the sum of squares due to error.

$$\begin{aligned} SS_T = SS_{strategy} &+ SS_{mode} + SS_{algorithm} + SS_{strategy/mode} \\ &+ SS_{strategy/algorithm} + SS_{mode/algorithm} \\ &+ SS_{strategy/mode/algorithm} + SS_E \end{aligned} \qquad (58)$$

The associated degrees of freedom are:

strategy:	(7-1) = 6
mode:	(2-1) = 1
algorithm:	(3-1) = 2
strategy/mode:	(7-1) (2-1) = 6
strategy/algorithm:	(7-1) (3-1) = 12
mode/algorithm:	(2-1) (3-1) = 2
strategy/mode/algorithm:	(7-1) (2-1) (3-1) = 12
Error:	(7) (2) (2) (72-1) = 6006
Total:	(7) (2) (2) (144) -1 = 6047

Each sum of squares divided by its respective degrees of freedom is the mean square. Under the assumption that the model, equation (51), is adequate and that the error terms are normally and independently distributed with constant variance, the following ratios of mean squares form the appropriate test statistics:

1. Do engagement strategy and algorithm interact?

$$F_o = \frac{MS_{strategy/algorithm}}{MS_E} \tag{59}$$

2. Do firing mode and algorithm interact?

$$F_o = \frac{MSE_{mode/algorithm}}{MS_e} \tag{60}$$

3. Do engagement strategy and firing mode interact?

$$F_o = \frac{MS_{strategy/mode}}{MS_E} \tag{61}$$

4. Are the effects of the algorithms significant?

$$F_o = \frac{MS_{algorithm}}{MS_E} \tag{62}$$

5. Is there a difference between firing in precision and battlesight mode?

$$F_o = \frac{MS_{mode}}{MS_E} \tag{63}$$

6. Are the engagement strategies different?

$$F_o = \frac{MS_{strategy}}{MS_E} \tag{64}$$

4.3.1.5 Multiple Comparisons. Should the tests above indicate the engagement strategies are not the same, multiple pairwise comparison tests of the factor mean

responses, or if interactions exist the treatment level means, will indicate their specific differences. Neter, Wasserman, and Kutner point out the following limitations of simple comparison of means testing.

> 1. The confidence coefficient $1 - \alpha$ applies only to a particular estimate, not to a series of estimates.
>
> 2. The confidence coefficient $1 - \alpha$ is appropriate only if the estimate was not suggested by the data. (21:579)

The Tukey HSD procedure will be used for these tests in order to hold the family confidence coefficient constant at .95 (21:580-583, 837).

4.3.2 Research Question #2. What is the most efficient burst size for expanding the initial engagement strategy to achieve the desire target effect?

A fire for effect phase to an engagement assumes that the initial eight rounds resulted in at least one target hit. Based on that assumption, the only controllable factor which might influence the Bradley gunnery process is the length of the killing burst. A single factor ANOVA experiment provides the means to compare the three burst lengths and determine if a 'best' kill burst exists within the limitations of this research.

4.3.2.1. The model. The second research question will be analyzed using the accumulated target hits out of 60 total rounds as the dependent variable. Without addressing the classified estimates of how many APDS-T rounds are

required to neutralize the various BMP versions, the accumulated number of target hits appears to be an adequate measure of effectiveness.

The single factor is the length of the killing burst in number of rounds. The three factor levels are: A = 3 round burst; B = 4 round burst; C = 5 round burst.

The linear statistical model is therefore:

$$Y_{ijk} = \mu + \tau_i + e_{ijk} \tag{65}$$

where

τ_i - *burst length a ... c*
e_{ij} - *random error for all j replications*

4.3.2.2 The hypotheses test.

Are the effects of the bursts different?

$$\begin{aligned} H_o&: \tau_a = \tau_b = \tau_c = 0 \\ H_a&: \text{at least one } \tau_i \neq 0 \end{aligned} \tag{66}$$

4.3.2.3 Level of significance and sample size.

Sample size for the experiment was also determined using the power approach. In order to detect a one standard deviation difference in the main effects, while limiting the risk of making a TYPE I error to .05 and a TYPE II error to .10, 27 replications are appropriate for this single factor experiment.

4.3.2.4 The test statistic. The total sums of squares for the model can be decomposed into the sum of

squares for the single factor and the sum of squares due to error.

$$SS_T = SS_{burst} + SS_E \tag{67}$$

where the associated degrees of freedom are:

burst: (3-1)=2
Error: (27-3)=24
Total: (27-1)=26

Each sum of squares divided by its respective degrees of freedom is the mean square. Under the assumption that the model, equation (65), is adequate and that the error terms are normally and independently distributed with constant variance, the following ratio of mean squares form the appropriate test statistic:

$$F_o = \frac{MS_{bursts}}{MS_E} \tag{68}$$

4.3.2.5 Multiple Comparisons. Should the test above indicate the mean number of hits according to burst length are not the same, the Tukey HSD procedure also will be used for multiple pairwise comparisons in order to hold the family confidence coefficient constant at .95 (21:580-583).

4.3.3 Model Adequacy. The inferences gained from the ANOVA methods can only be used if the underlying models prove adequate. The two ANOVA model assumptions will be checked using residual analysis. A normal probability plot of residuals will be used to determine if the error terms

are normally and independently distributed. The constant variance assumption will be verified using plots of the residuals versus the fitted response values and engagement strategies. (20:210-213; 21:609-611,613-614)

V. *RESULTS*

This chapter summarizes and discusses the results from the experimental design outlined in Chapter 4. The discussion is divided into two parts which correspond to Research Questions 1 and 2. The results are addressed in relatively generic terms, with only limited explanation as to how they relate to Bradley gunnery techniques. Specific conclusions about the practical significance of the findings and their potential impact on gunnery will be discussed in Chapter 6.

5.1 Research Question #1. What is the best engagement strategy for the BFV 25-mm firing APDS-T ammunition at a BMP-type target?

Eight hypothesis tests were purposed in order to answer this question. The first four determine if any significant interactions exist; the presence of which would complicate the analysis. Specifically, the tests determine the sensitivity of model results to changes in the YAKIMA Aim Point Adjustment Algorithm. Based on the results of these tests, the fifth test checks the significance of using the precision versus battlesight mode of target engagement. The final test, as well as follow-on multiple comparison tests, focus on determining if a 'best' engagement strategy exists. The ANOVA table below summarizes the results.

Analysis of Variance Procedure

Dependent Variable: TARGET KILLS

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	41	192133.2	4686.2	215.8	0.0001
STRATEGY	6	89522.6	14920.4	687.2	0.0001
ALGORITHM	2	88102.2	44051.1	2028.9	0.0001
MODE	1	6812.8	6812.8	313.8	0.0001
ALGORITHM*STRATEGY	12	5780.7	481.7	22.2	0.0001
ALGORITHM*MODE	2	1700.9	850.5	39.2	0.0001
MODE*STRATEGY	6	113.1	18.9	0.9	0.5463
ALGOR*MODE*STRATEGY	12	100.8	.4	0.4	0.9687
Error	6006	130399.8	21.7		
Total	6047	322533.0			

5.1.1 Influence of YAKIMA Aim Point Adjustment Algorithm. Assumptions concerning the validity of the Yakima algorithm will significantly influence the conclusions that may be drawn from this research. Although the three-way interaction (algorithm/mode/strategy) is not significant, the ANOVA results show a significant interaction of the algorithm factor with both firing mode and engagement strategy. The main factor effect is also highly significant. As noted in Chapter 4, the presence of an interaction between the algorithm factor and engagement strategy means that the model results are not robust to changes to the aimpoint adjustment algorithm. As a result, the engagement strategies may only be evaluated within a specific level of the algorithm factor. Interpretation of the model's sensitivity to the YAKIMA algorithm assumption

can be enhanced using a graphic representation. See Figure 15.

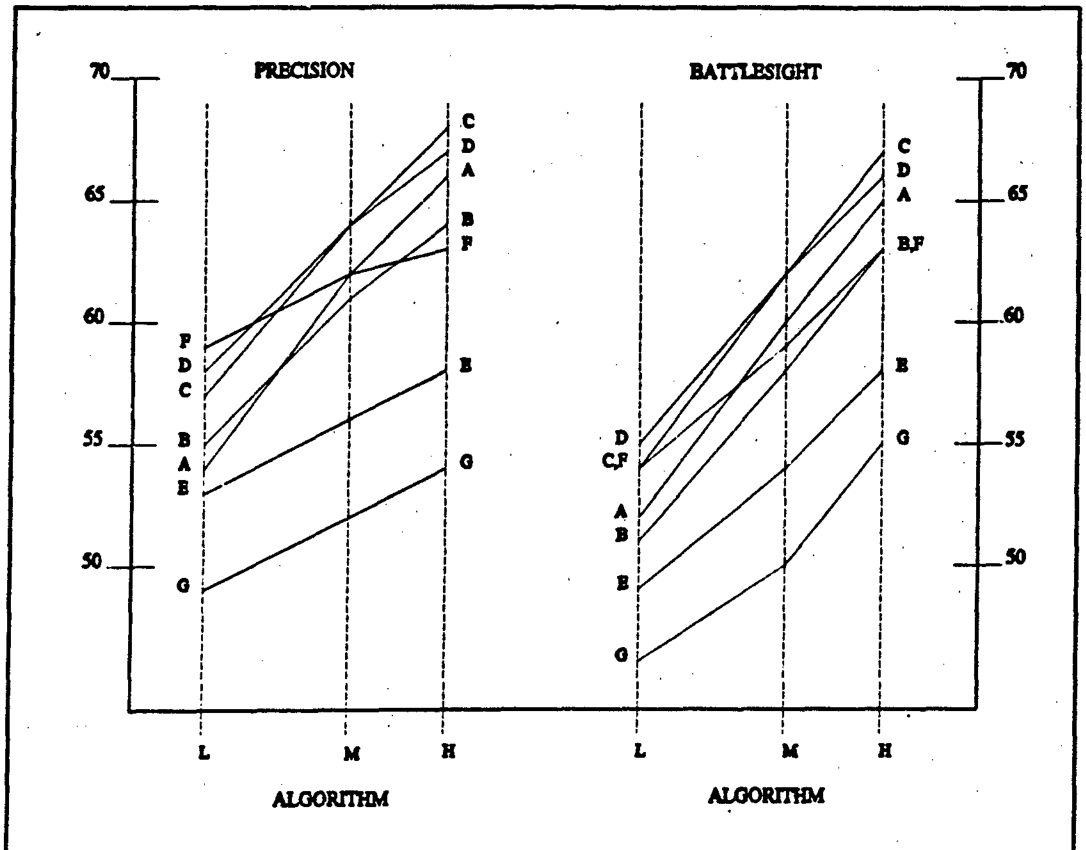


Figure 15. Interpretation of the YAKIMA Assumption on Model Results

The graphs highlight the dramatic and intuitive influence changes to the algorithm factor levels have on overall performance regardless of the various engagement procedures employed. This represents the influence of the main factor effect. An average aim point correction of 30 percent of target miss distance (L) yields extremely low results in relation to an average correction of either 60 percent (M) or 80 percent (H).

Changes to the algorithm levels have a greater influence on performance in the battlesight mode than in precision mode as evidenced by the steeper slope of the connecting lines. This result is also intuitive. Battlesight procedures depend on a relatively conservative GO/NO GO type of range to target estimation. The resulting ISU index range of either 1200 or 1600 meters creates an inherently larger initial aiming error. In contrast, the additional accuracy in target range estimation using precision gunnery procedures decreases the initial miss distance due to aim error. Therefore, the required aim point adjustments in the battlesight mode will usually be larger and more significantly affected by the accuracy of the adjustment procedure. It should be noted, however, that as the adjustment procedures improve, the difference in relative performance between firing modes is less pronounced. The mean target kills over all engagement strategies for each combination of algorithm and firing mode are listed below.

Level of ALGORITHM	Level of MODE	Mean TARGET KILLS
H	P	62.95
H	B	62.02
M	P	60.05
M	B	58.11
L	P	55.00
L	B	51.49

The algorithm/engagement strategy interaction also exhibits a reasonable set of trends which the graphs highlight. As the aim point algorithm improves in accuracy those engagement strategies which consist of four shoot-look-adjust-shoot combinations and/or employ more than one sensing round show a more dramatic improvement in the number of target kills. The slope of the connecting lines for these strategies (A, B, C, D) are much steeper. Since the range-in process is extended in these strategies, the aim point has been further refined prior to firing the first killing burst; resulting in an improved hit probability for these subsequent bursts. This result is consistent with AMSAA's findings using the HITPROB2 model to determine a distribution for the number of rounds required to range-in targets at various fixed ranges. Table 7 shows AMSAA estimates for the probability of range-in based on the number of sensing rounds fired and the average number of rounds required to range-in targets at various ranges.

TABLE 7

Cumulative Range-in Probabilities
and
Average Number of Range-in Rounds
(18:6-7)

Range	Number of Range in Rounds 1	2	3	Average # Required
800	0.952	0.979	0.991	1.2
1200	0.813	0.904	0.947	1.8
1600	0.619	0.772	0.867	2.6
2000	0.444	0.625	0.754	3.5

The results depicted in Figure 15 also lead the research directly back to the YAKIMA algorithm itself. As noted in Chapter 3, AMSAA's documentation states that the YAKIMA method

> quantifies the correction of miss distance. **The quantities calculated are the mean percent correction of the miss distance on the preceding round, and the standard deviation thereof.** ... The final mean correction was 0.4D with a standard deviation of 0.7D where **correction is the adjustment made.** (2:18) *(emphasis added)*

The coded algorithm, however, actually calculates the impact coordinates for the next round based on a mean correction of 60 percent rather than 40 percent. See Figure 16.

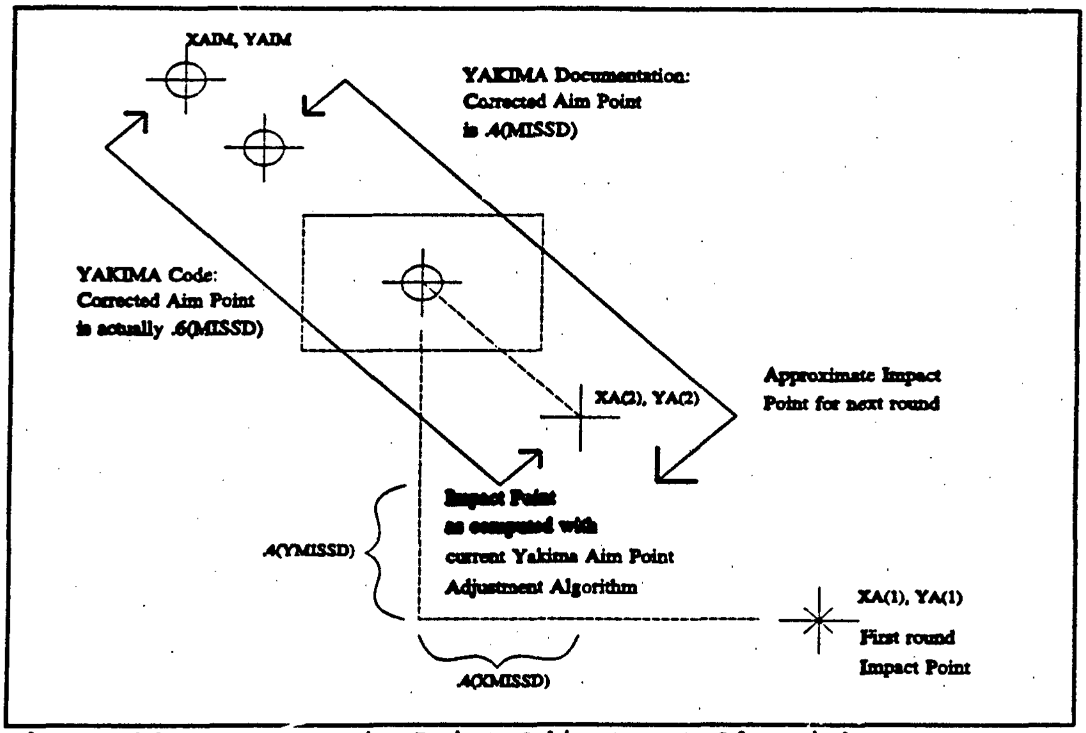


Figure 16. YAKIMA Aim Point Adjustment Algorithm

The author's practical Bradley gunnery experience leads to the assumption that the coded algorithm is a more accurate representation of an average Bradley crew's ability to apply BOT adjustment procedures. The remainder of the results presented will be based on that assumption. The obvious discrepancy between the coded algorithm and the written documentation only serves to place additional emphasis on understanding the potential influence of the YAKIMA algorithm proving to be incorrect.

5.1.2 Firing Mode Influences. The ANOVA results indicate that the difference in performance between precision and battlesight mode engagements is statistically significant. As noted above, however, the level of

significance is also dependent on the accuracy of the aim point adjustment algorithm. Further, the results show no significant interaction between firing mode and engagement strategy.

5.1.3 Influence of Engagement Strategies. The ANOVA table shows a significant difference exits between the various engagement strategies. The nature of these differences become apparent from the results of multiple pairwise comparisons using the Tukey Honestly Significant Difference (HSD) method. Based on the assumption that the current YAKIMA algorithm is correct, only the comparisons of factor level means for the ***M*** level of the algorithm factor are presented. See Table 8.

TABLE 8

Tukey's Studentized Range (HSD) Test

Alpha= 0.05 df= 2002 MSE= 21.7116
Critical Value of Studentized Range= 4.171
Minimum Significant Difference= 0.8894

Means with the same letter are not significantly different.

STRATEGY	Tukey Grouping	Mean
1-2-2-3 (D)	A	63.16
	A	
1-1-3-3 (C)	A	62.90
1-1-1-5 (A)	B	60.88
	B	
1-3-4 (F)	B	60.72
1-1-2-4 (B)	C	59.47
1-2-5 (E)	D	55.20
2-3-3 (G)	E	51.24

5.2 *Research Question #2.* What is the most efficient burst size for expanding the initial engagement strategy to achieve the desired target effect?

The single hypothesis test purposed to answer this question evaluates whether a significant difference in mean target hits occurs using three, four, or five round killing bursts during the extended fire for effect stage of an engagement. Statistical tests proved unnecessary after compiling the data from the experiment. The mean difference was so large, that statistical significance was not a question. Table 9 summarizes the results. They indicate that a very significant difference exists between the burst lengths.

TABLE 9

Target Hits by Burst Length

Burst Length	Mean Target Hits	Group Standard Deviation
3	30.263	0.0288
4	40.273	0.0294
5	50.276	0.0240

5.3 *Model Adequacy*

The ANOVA model used for the tests above appears to be adequate. The normal probability plot was unremarkable.

Plots of the residuals versus the fitted response values displayed no systematic patterns that would indicate that an assumption of constant variance was inappropriate. Given the general robustness of ANOVA to small departures from the model assumptions, there exists no reason to question the aptness of the model or its results.

VI. *CONCLUSIONS AND RECOMMENDATIONS*

This chapter will discuss the experimental results in response to the research questions and, where appropriate, draw conclusions which relate the gunnery process as simulated by the model POINT TARGET ENGAGEMENT to actual techniques and procedures. Based on these conclusions as well as the limited scope of this research, recommendations for further study will also be included.

In the introduction to his book, Design and Analysis of Experiments, Montgomery states:

> Once the data has been analyzed, the experimenter must draw **practical** conclusions about the results and recommend a course of action. ... Just because two experimental conditions produce mean responses that are statistically different, there is no assurance that this difference is large enough to have any practical value. (20:11,13)

This distinction will guide the comments which follow.

6.1 Engagement Strategy

The results indicate a definite ordering of engagement strategies. Figure 17 is a bar chart which shows the relative performance of the seven tested strategies. The appearance of significant difference between the strategies is obvious, however, the range of mean target kills from the 'best' to the 'worst' strategy is only twelve targets. The difference between the top two groups of statistically significant strategies is only two targets. A quick

practical answer to the first research question might seem to be: There is no best engagement strategy. Despite these initial observations, several additional considerations revealed by the results may provide a greater level of insight and lead to a totally different conclusion.

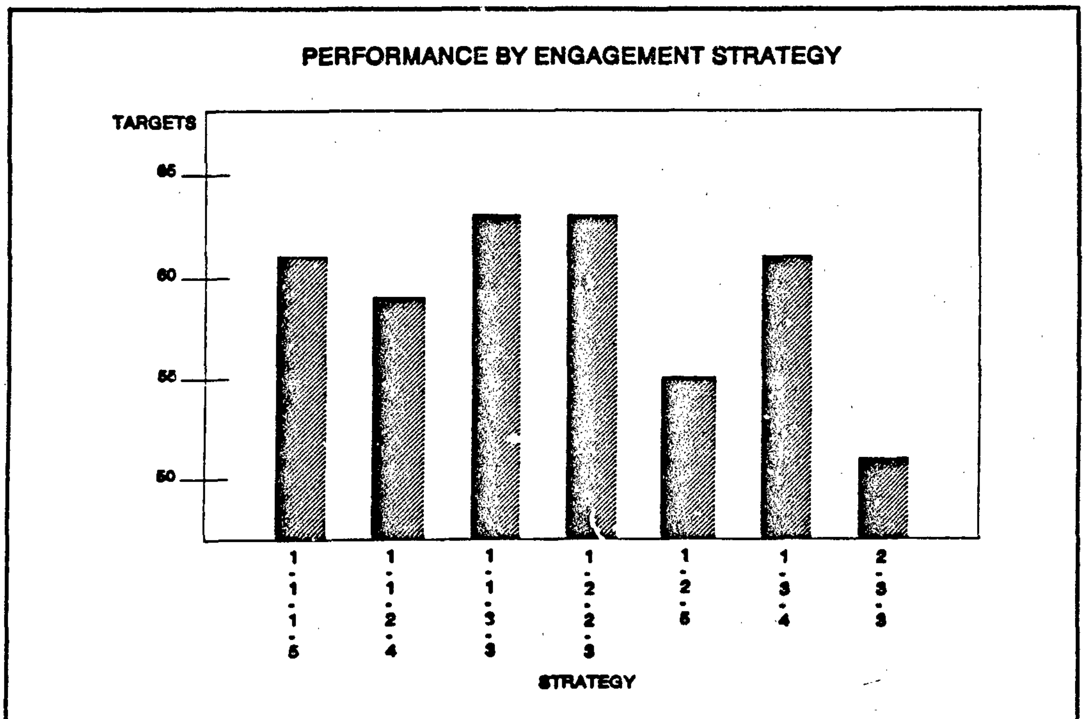


Figure 17. Engagement Strategy Comparison

Time is also an important aspect of an engagement which was only considered indirectly in this research under the assumption that only four shoot-look-adjust-shoot iterations were feasible. The two best strategies in the results employ four iterations; while one of the next two ranking strategies, {1-3-4}/{1-4-3}, uses only three iterations. There is an obvious time versus accuracy tradeoff that must

be resolved. However, two additional issues should be considered: moving targets and the BOT adjustment process.

An identified limitation of this research is that only stationary Bradley versus stationary BMP targets are considered. Moving target engagements add the complicating factor of an aim point which must lead the target to compensate for the movement. Simple in concept, but often difficult in practice, the application of lead rules to various combinations of target speeds and target aspect angles are recommended by *FM 23-1* (5:4_28-4_21). The logical assumption, supported by a similar trend in the results of this research, is that strategies with four iterations or which employ more than one single sensing round will be more successful. Thus, engagement strategies {1-1-3-3} and {1-2-2-3} may be more clearly superior if moving targets are considered.

A more subtle conclusion can be drawn from the results of the YAKIMA algorithm sensitivity analysis. The YAKIMA algorithm models the BOT direct fire adjustment procedure. Whether its estimate of average Bradley crew performance is accurate or not, the algorithm correctly captures the physical process. If the remainder of the POINT TARGET ENGAGEMENT model is assumed to be a valid or at least a credible representation of the Bradley 25-mm gun system, the trends reflected by the engagement strategy/algorithm interaction may suggest similar results in actual Bradley

crew performance. As the mean accuracy of the correction algorithm changed from 30 to 80 percent, engagement strategies with four iterations showed a greater degree of improvement. The strategy {1-1-1-5} displayed the most dramatic overall improvement, however, the use of three single sensing rounds seems extreme. Strategies {1-1-3-3} and {1-2-2-3} were consistently the best across the entire range of correction algorithm accuracy.

BOT techniques are highly trainable at the unit level using the Unit Conduct of Fire Trainer (UCOFT) which is a crew interactive Bradley gunnery simulator. Given the assumption of model validity, as a crew's proficiency increases through training, the use of either engagement strategy {1-1-3-3} or {1-2-2-3} seems to provide the greatest potential for an accompanying improvement in overall gunnery performance.

The quick answer to the first research question suggested above is clearly inappropriate. The model results as well as inferences drawn from them lead to the conclusion, considered both statistically and practically sound, that the best engagement strategies are {1-1-3-3} and {1-2-2-3}. This conclusion should be verified, however, by further study which includes both moving targets and a time/accuracy trade-off analysis.

6.2 *Battlesight Versus Precision Gunnery.*

The results clearly show that the difference between firing in precision mode and battlesight mode is statistically significant. Figure 18 shows a comparison between precision and battlesight mode results.

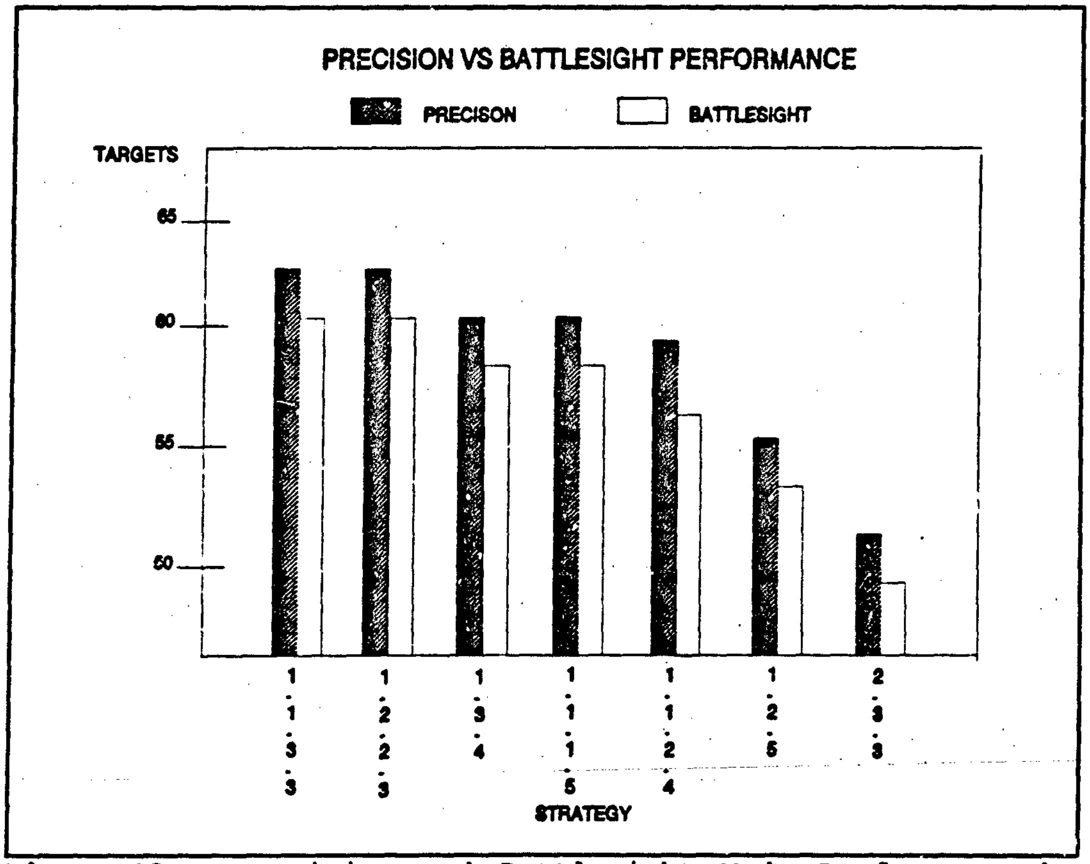


Figure 18. Precision and Battlesight Mode Performance by Engagement Strategy

The mean difference across all strategies is only two target kills. The most likely explanation for the limited difference in performance is that any additional accuracy in range estimation using precision gunnery procedures are all but canceled out by the comparatively imprecise 200 meter

increments of the ISU range index knob. Here the quick practical answer appears to be appropriate. The same issues of time of the engagement, moving targets, and crew BOT proficiency can be used to further argue that there is no practical difference between the two procedures.

It was noted in Chapter 1 that the principal drawback to the range estimation procedures required in precision gunnery was the amount of time required to employ them. Use of the choke sight to estimate target range involves a procedure totally distinct from placing the sight reticle on the visible center mass of the target. In contrast, the range estimation procedure used to determine whether the battlesight range index should be 1200 or 1600 is based on the appearance of the target in relation to the sight reticle itself. See Figure 19.

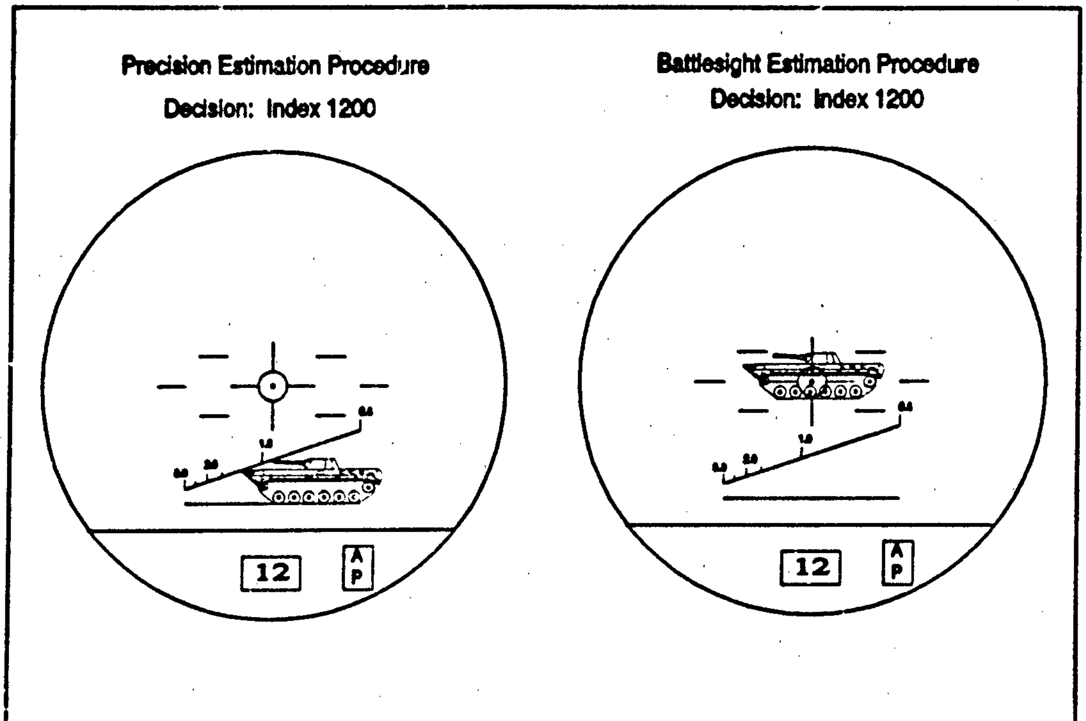


Figure 19. Comparison of Range Estimation Procedures

The choke sight procedure obviously takes more time. The time difference will also probably increase if the target is moving. A time/accuracy trade-off analysis could determine the significance of the two procedures on overall performance, however it is reasonable to assume that the performance margin would narrow.

The margin of difference also decreased as the accuracy of the model's aim point algorithm improved. The mean difference closed from three targets at algorithm level (L) to just one target at level (H). See Figure 20.

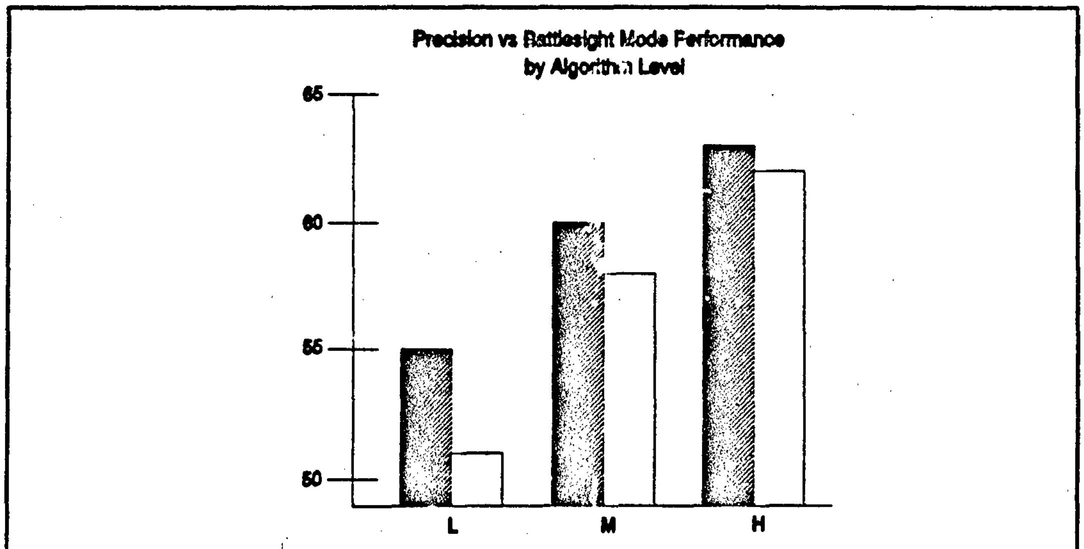


Figure 20. Comparison of Battlesight and Precision Gunnery Performance

Based again on the assumption that the model is a credible representation of the true gunnery process, the trend in the results lead to the conclusion that battlesight gunnery procedures should be used at all times. The assumptions noted in the development of this conclusion concerning time/accuracy trade-off and moving target engagements should be verified by additional study.

6.3 Fire for Effect Bursts

In response to Research Question #2, the results clearly indicate that five rounds is the best burst length in terms of cumulative accuracy during the extended fire for effect phase of an engagement. This seems to indicate that the cumulative character of the burst-to-burst and with-in burst dispersions are not overly large in comparison to the

size of the target. There is obviously not a loss in accuracy using a five round burst, that firing a shorter burst would overcome by fine tuning the aim point once a target hit occurs. The results probably also reflect a 'over-correction' effect which impacts more heavily as the number of aimpoint corrections increase. In reality, gunners also develop the ability to 'walk' longer bursts into the center of the target which could make the difference in relative performance even more significant. This effect was noted in the results of a live-fire test conducted by AMSAA from 11-15 September 1992 (13). Whether this technique significantly improves the accuracy of either three, four or five round bursts has not been determined. It may be feasible for a five round bursts, but not for three and four round bursts.

A logical extension to this research involves determining what is the trade-off in time versus number of total rounds expended to achieve a mobility or firepower kill using each of the burst lengths. This study would involve working with the classified estimates of 25-mm APDS-T lethality against the several BMP variants in use throughout the world. The utility of this effort is limited and probably not warranted.

6.4 Recommendations for Further Study

The recommendations in sections 1 and 2 above are

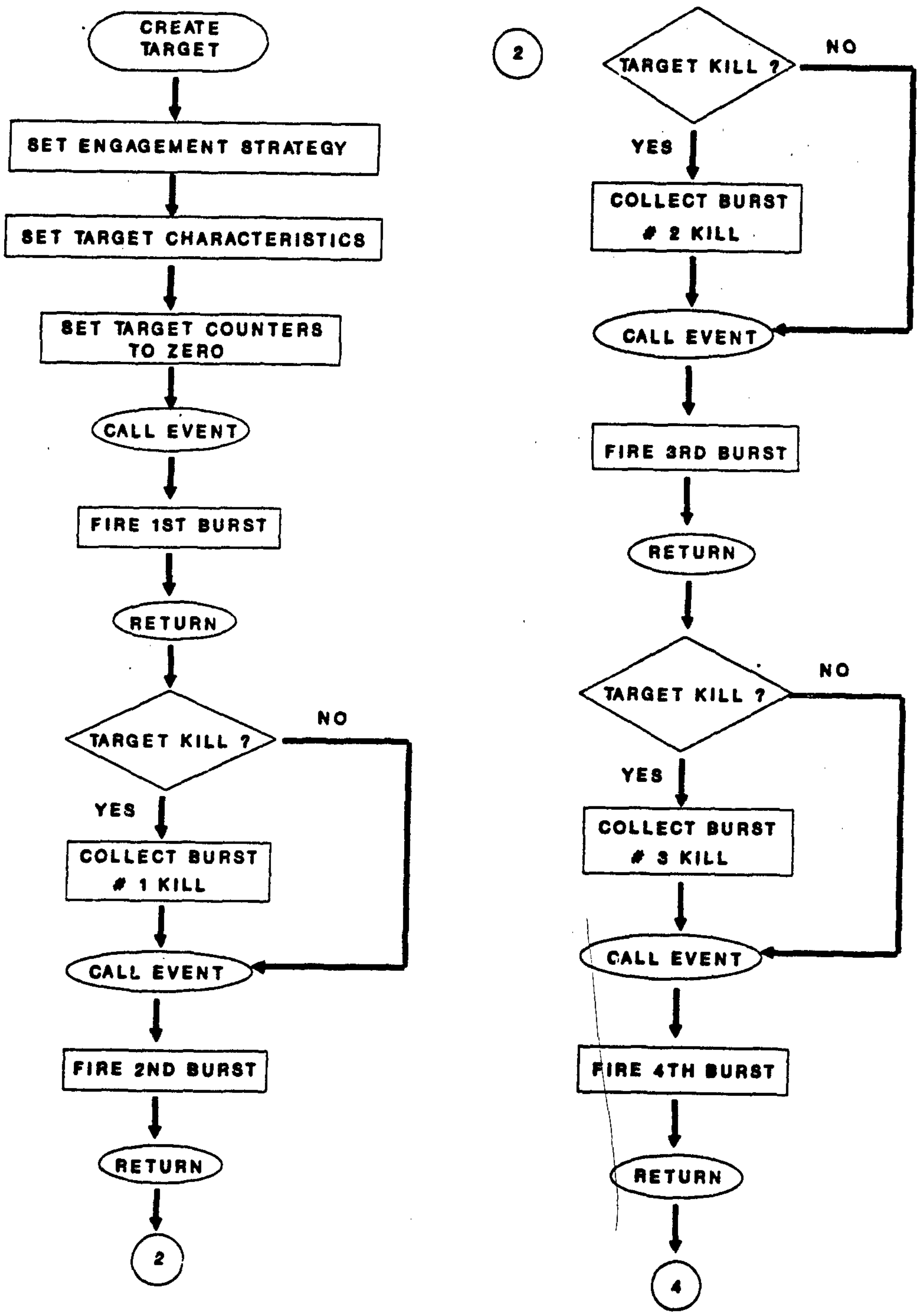
worthy of additional research. The conclusions based on results and inferences to this point will probably not prove compelling to the Bradley Community at large. The conclusion that precision gunnery is impractical will be especially controversial. The inclusion of elapsed time and moving targets to the engagement process would either dispel criticism or disprove the conclusions of this research. Two possible approaches could be used.

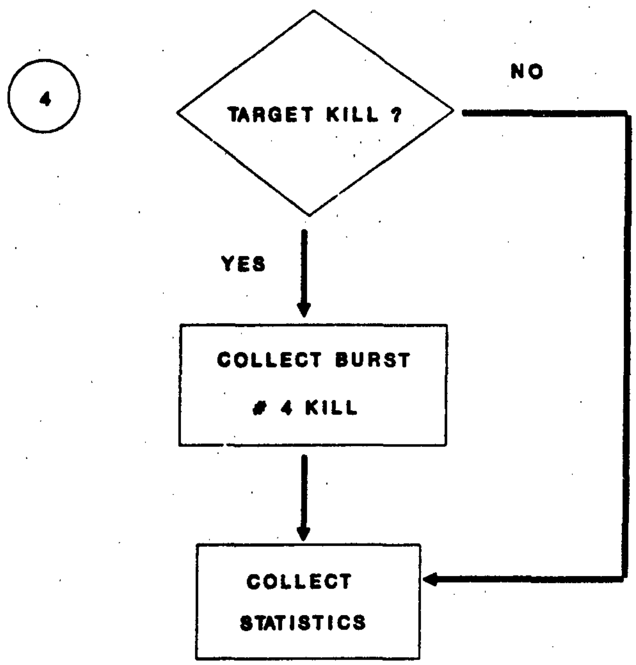
The POINT TARGET ENGAGEMENT model could be modified to include the aspects of time and movement. The SLAM based shell of the simulation seems to be capable of handling this modification, however, another simulation language may be more appropriate. This approach has the continued problem of model accreditation.

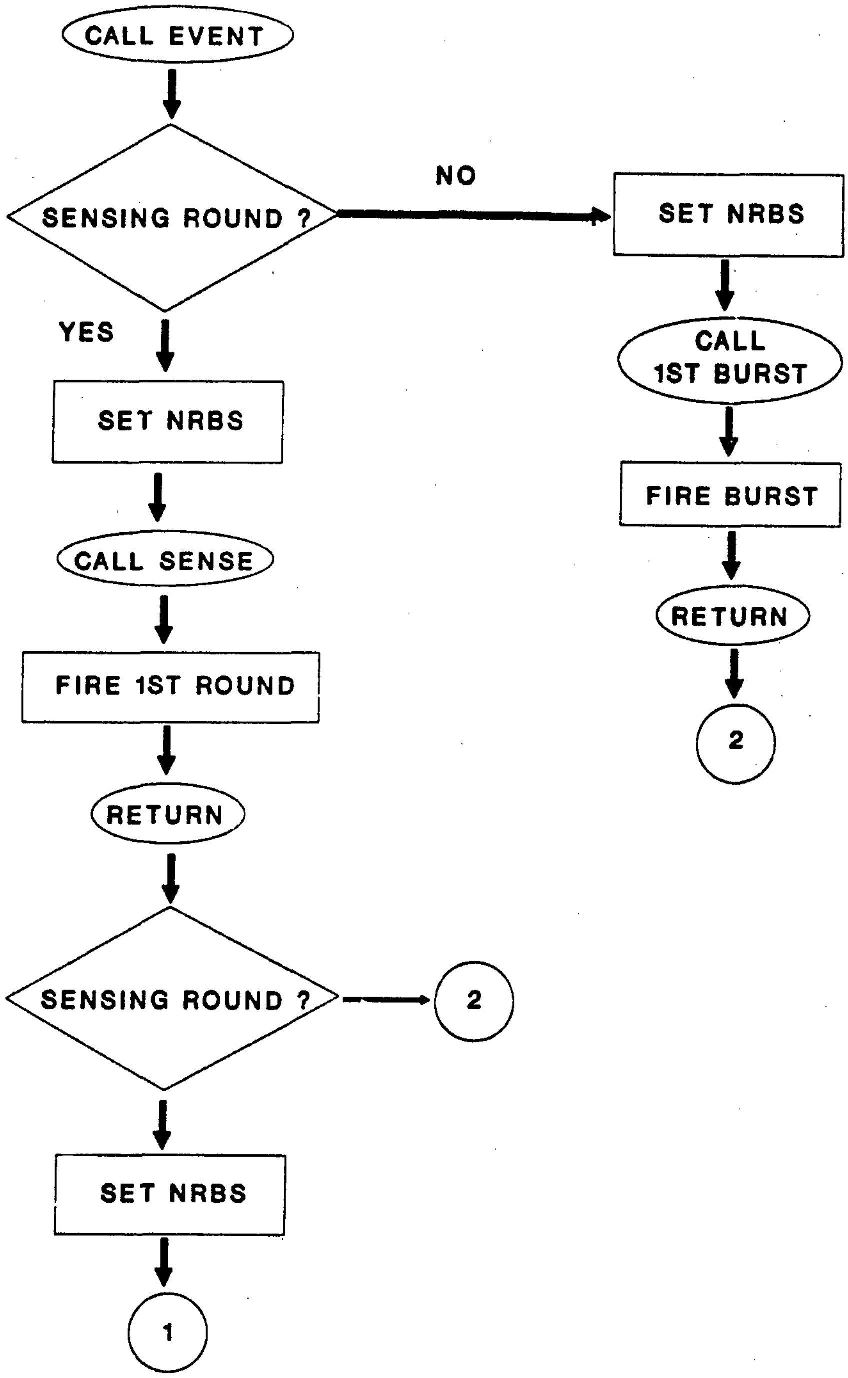
A second approach is to conduct the experiment using the Unit Conduct of Fire Trainer (UCOFT). Based on its use throughout the Army for gunnery sustainment training, the UCOFT simulator has developed a high level of at least face-validity. It has the capability to produce and perfectly replicate any number of moving and stationary engagement combinations while maintaining real time measures of crew and weapon system performance. A study of this type would undoubtedly require the cooperation and support of the Bradley Proponent at Fort Benning, Georgia.

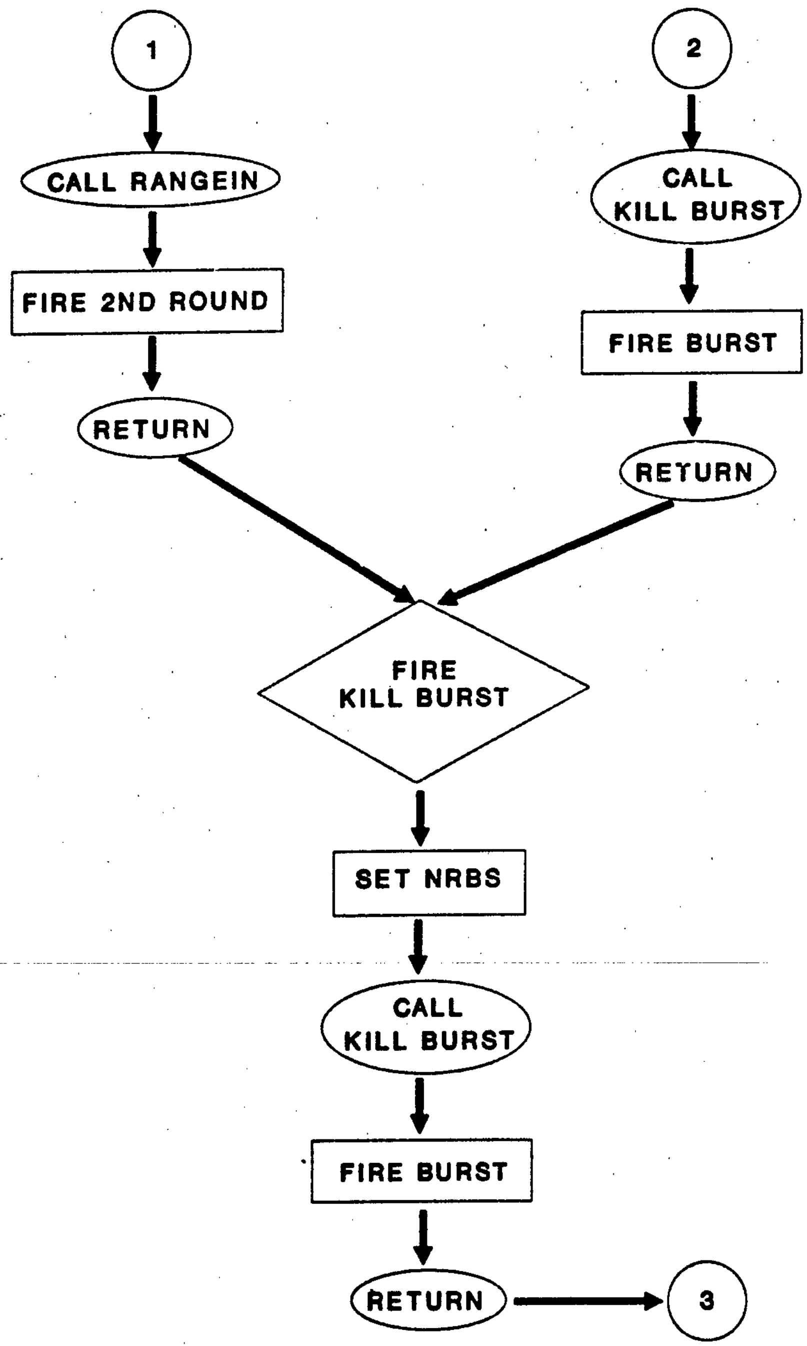
Appendix A: Simulation Model Flowcharts

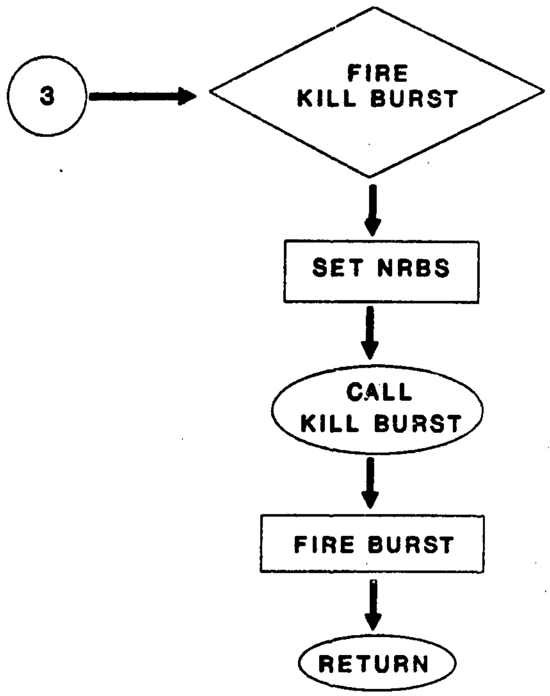
This appendix contains the flowcharts for the POINT TARGET ENGAGEMENT simulation model.

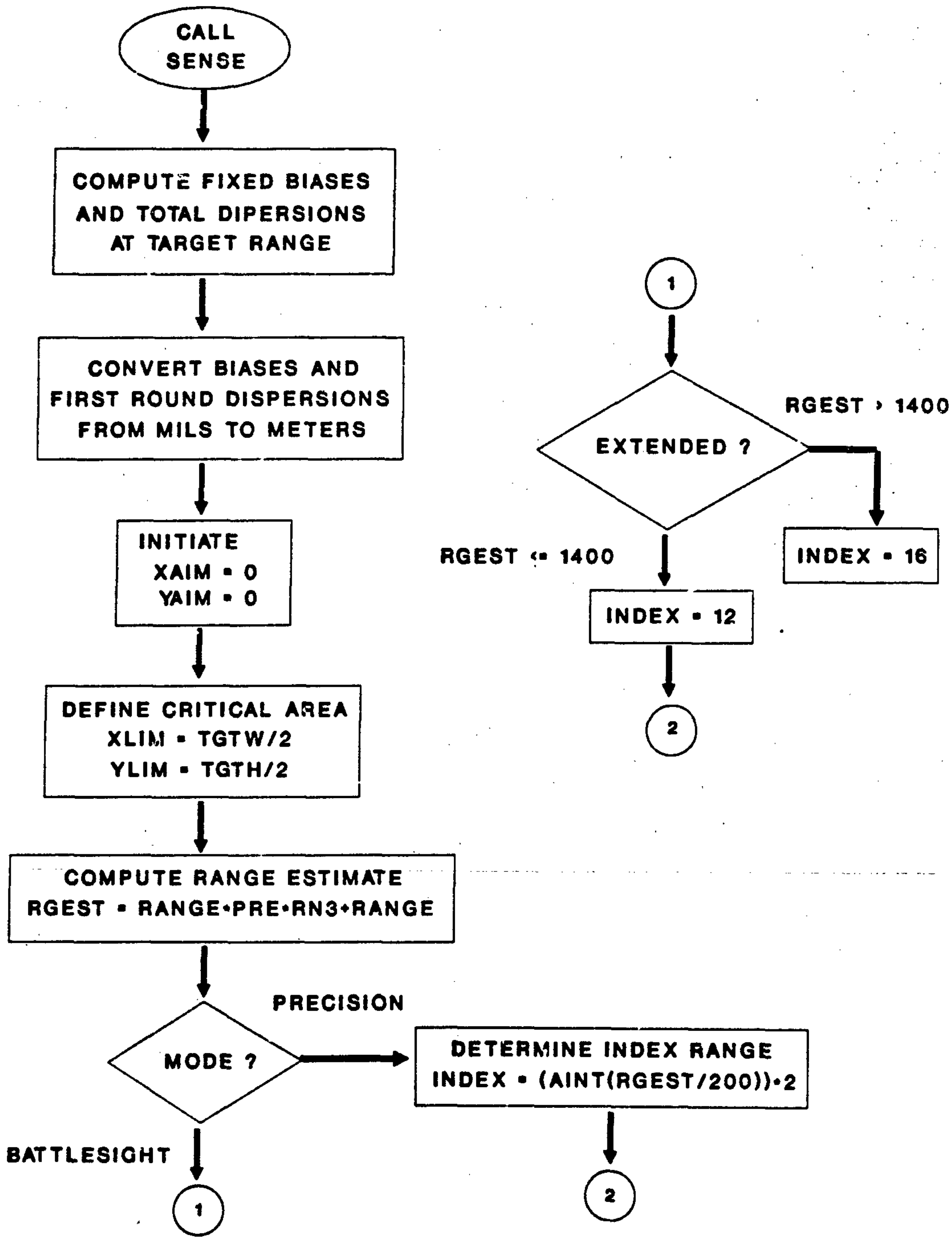

CREATE TARGET
SET ENGAGEMENT STRATEGY
SET TARGET CHARACTERISTICS
SET TARGET COUNTERS TO ZERO
CALL EVENT
FIRE 1ST BURST
RETURN
TARGET KILL ?
NO
YES
COLLECT BURST # 1 KILL
CALL EVENT
FIRE 2ND BURST
RETURN
2
2
TARGET KILL ?
NO
YES
COLLECT BURST # 2 KILL
CALL EVENT
FIRE 3RD BURST
RETURN
TARGET KILL ?
NO
YES
COLLECT BURST # 3 KILL
CALL EVENT
FIRE 4TH BURST
RETURN
4


4
TARGET KILL ?
NO
YES
COLLECT BURST
4 KILL
COLLECT
STATISTICS

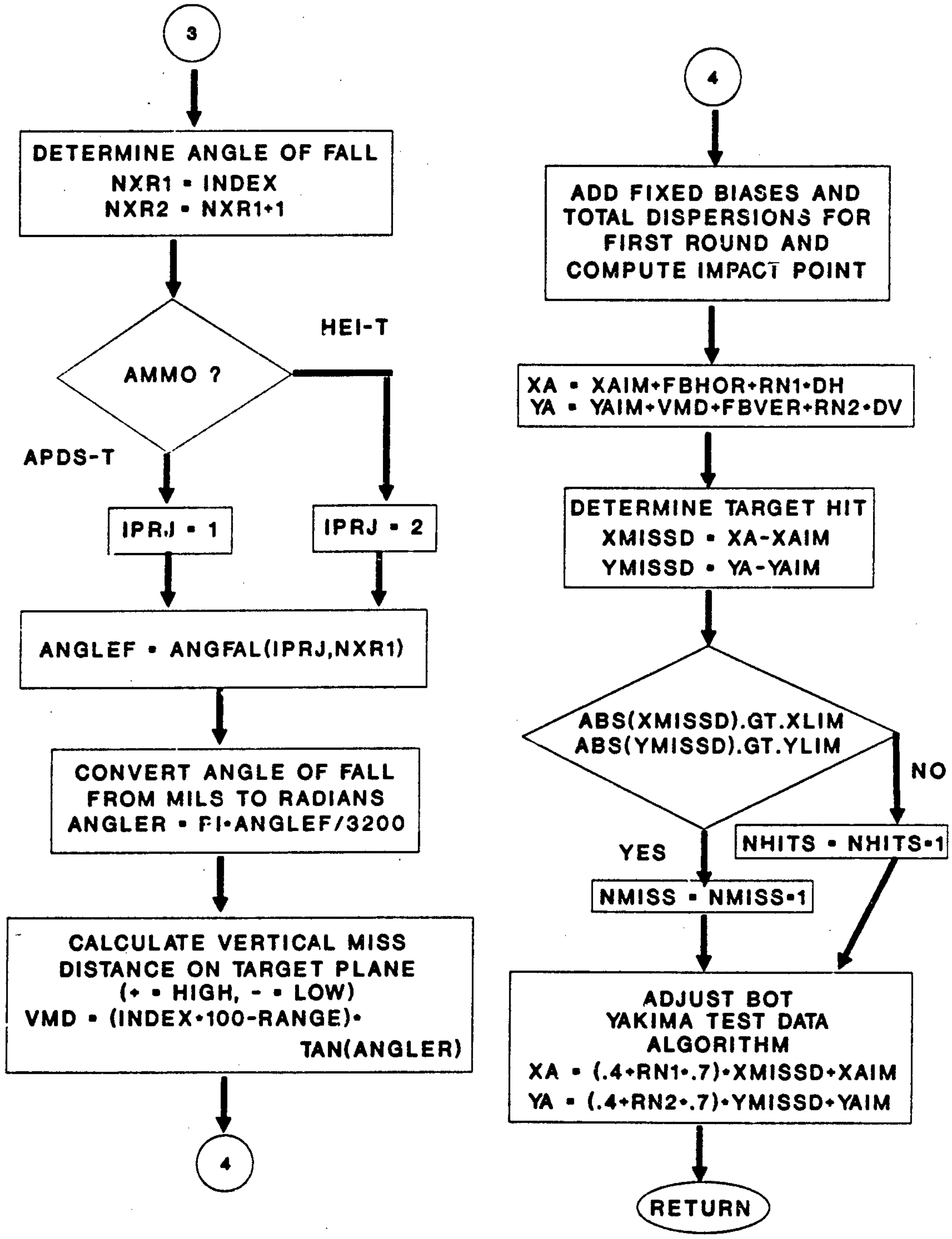

CALL EVENT
SENSING ROUND ?
NO
YES
SET NRBS
CALL 1ST BURST
FIRE BURST
RETURN
2
SET NRBS
CALL SENSE
FIRE 1ST ROUND
RETURN
SENSING ROUND ?
2
SET NRBS
1

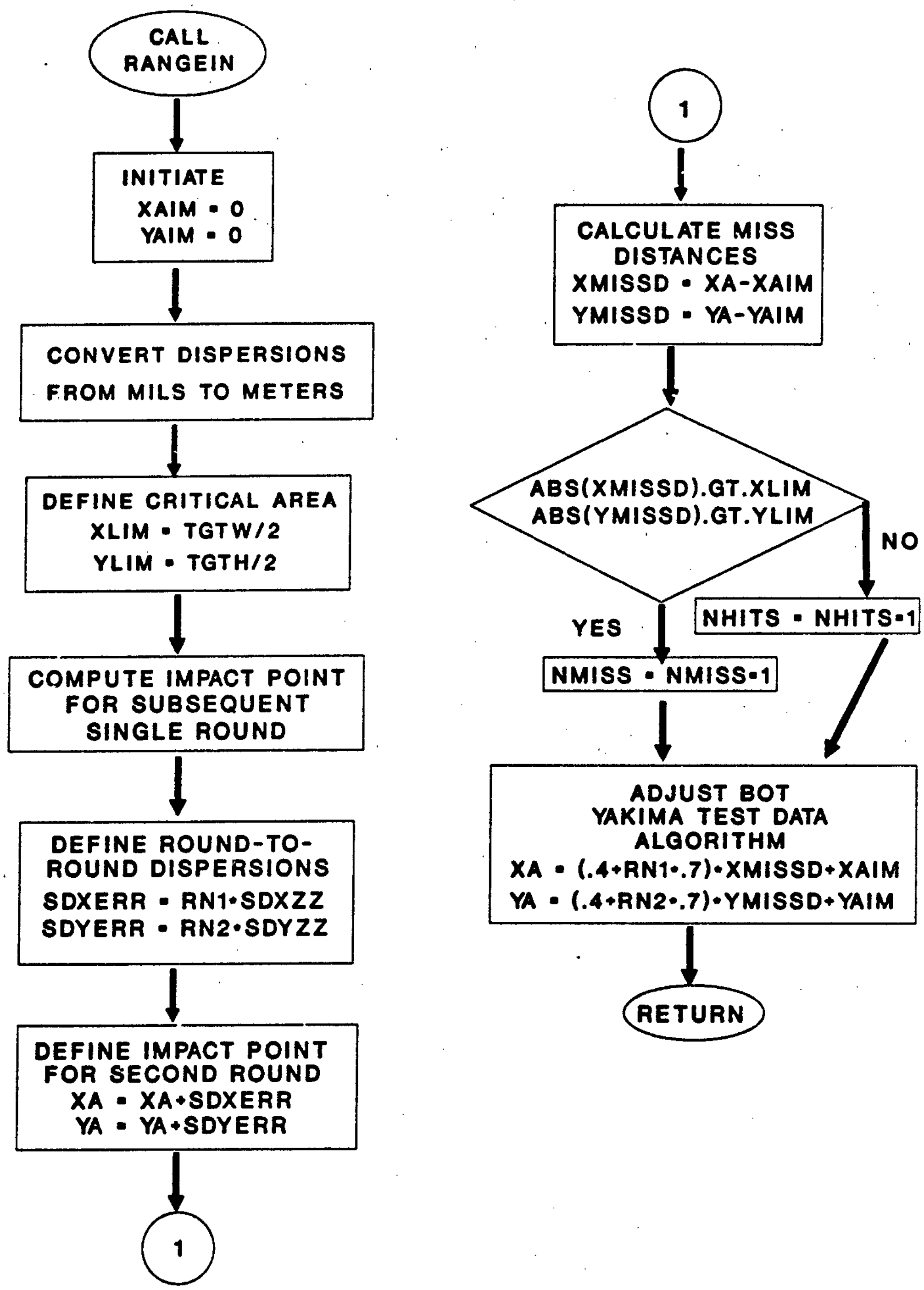

1
CALL RANGEIN
FIRE 2ND ROUND
RETURN
2
CALL
KILL BURST
FIRE BURST
RETURN
FIRE
KILL BURST
SET NRBS
CALL
KILL BURST
FIRE BURST
RETURN
3

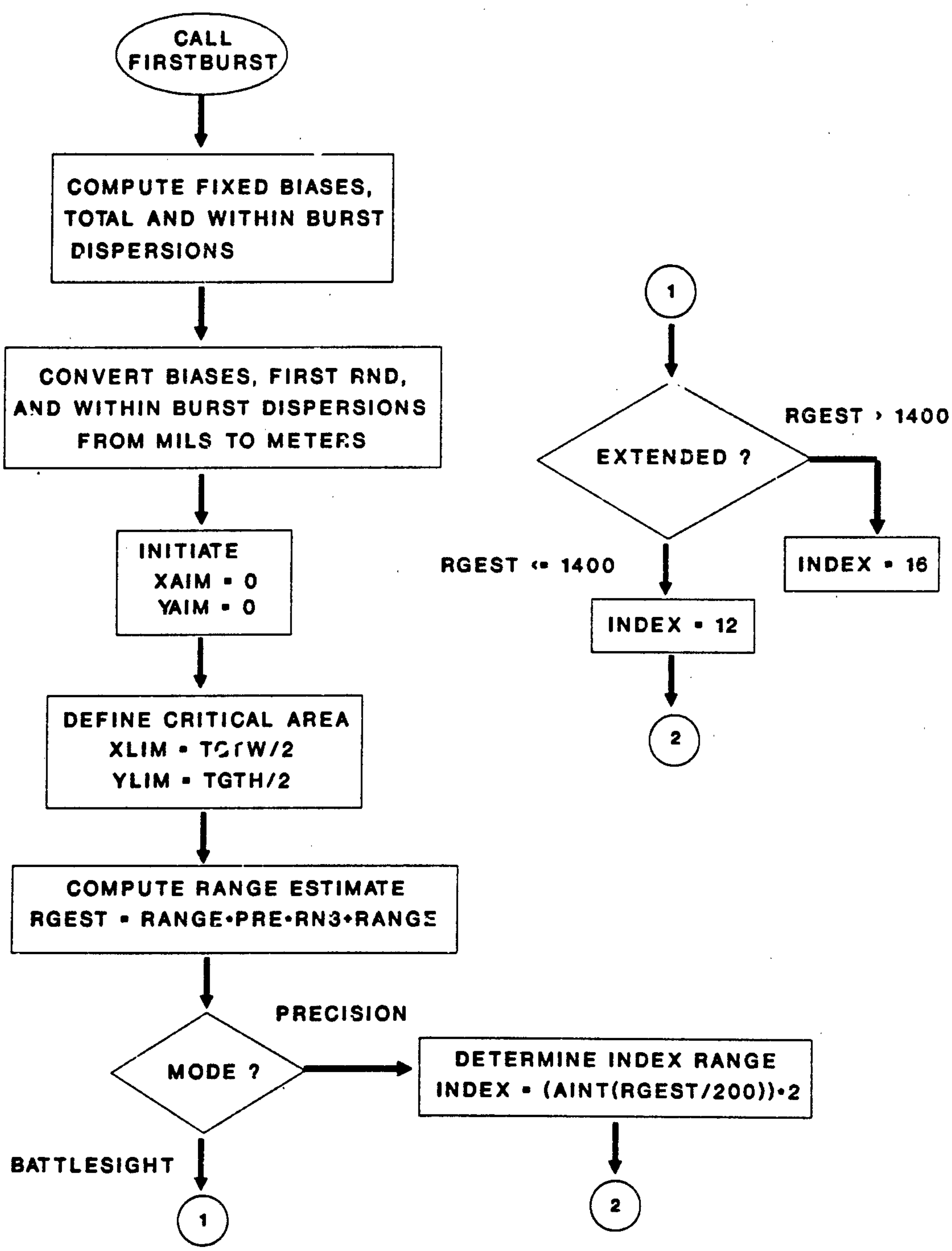

3
FIRE
KILL BURST
SET NRBS
CALL
KILL BURST
FIRE BURST
RETURN

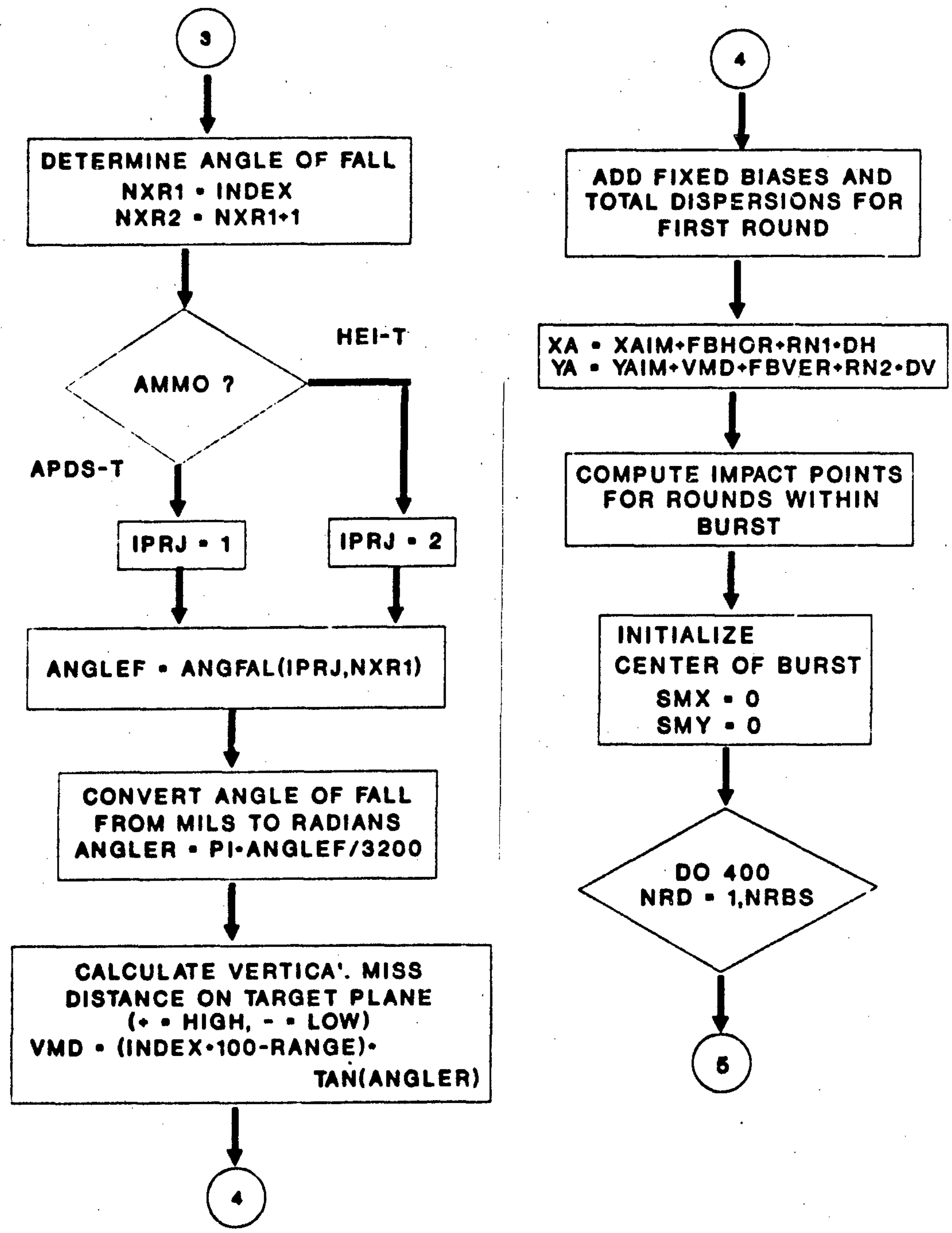


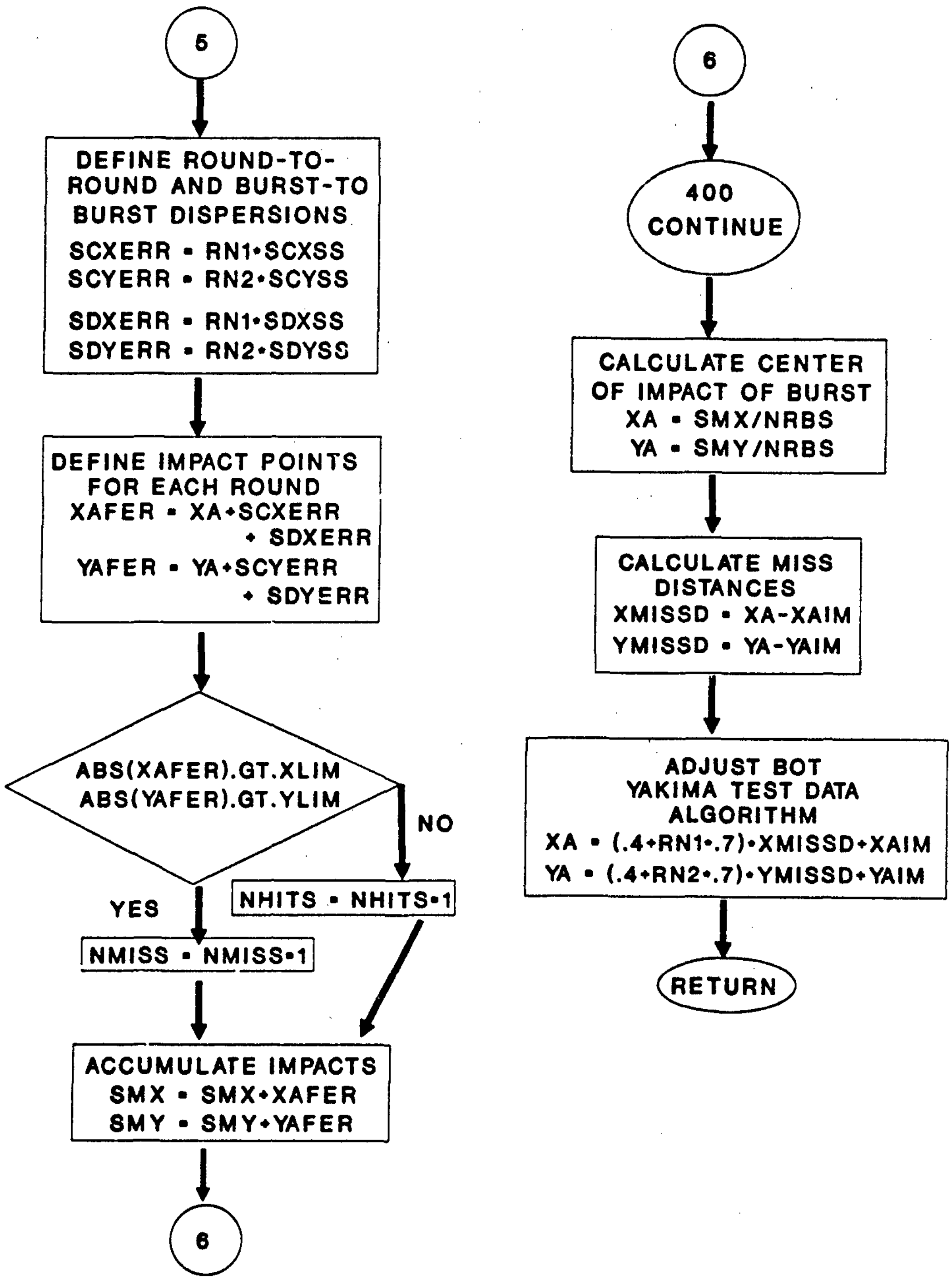
CALL SENSE
COMPUTE FIXED BIASES AND TOTAL DIPERSIONS AT TARGET RANGE
CONVERT BIASES AND FIRST ROUND DISPERSIONS FROM MILS TO METERS
INITIATE XAIM = 0 YAIM = 0
DEFINE CRITICAL AREA XLIM = TGTW/2 YLIM = TGTH/2
COMPUTE RANGE ESTIMATE RGEST = RANGE*PRE*RN3+RANGE
MODE ?
PRECISION
DETERMINE INDEX RANGE INDEX = (AINT(RGEST/200))*2
BATTLESIGHT
1
2
1
EXTENDED ?
RGEST > 1400
INDEX = 16
RGEST <= 1400
INDEX = 12
2

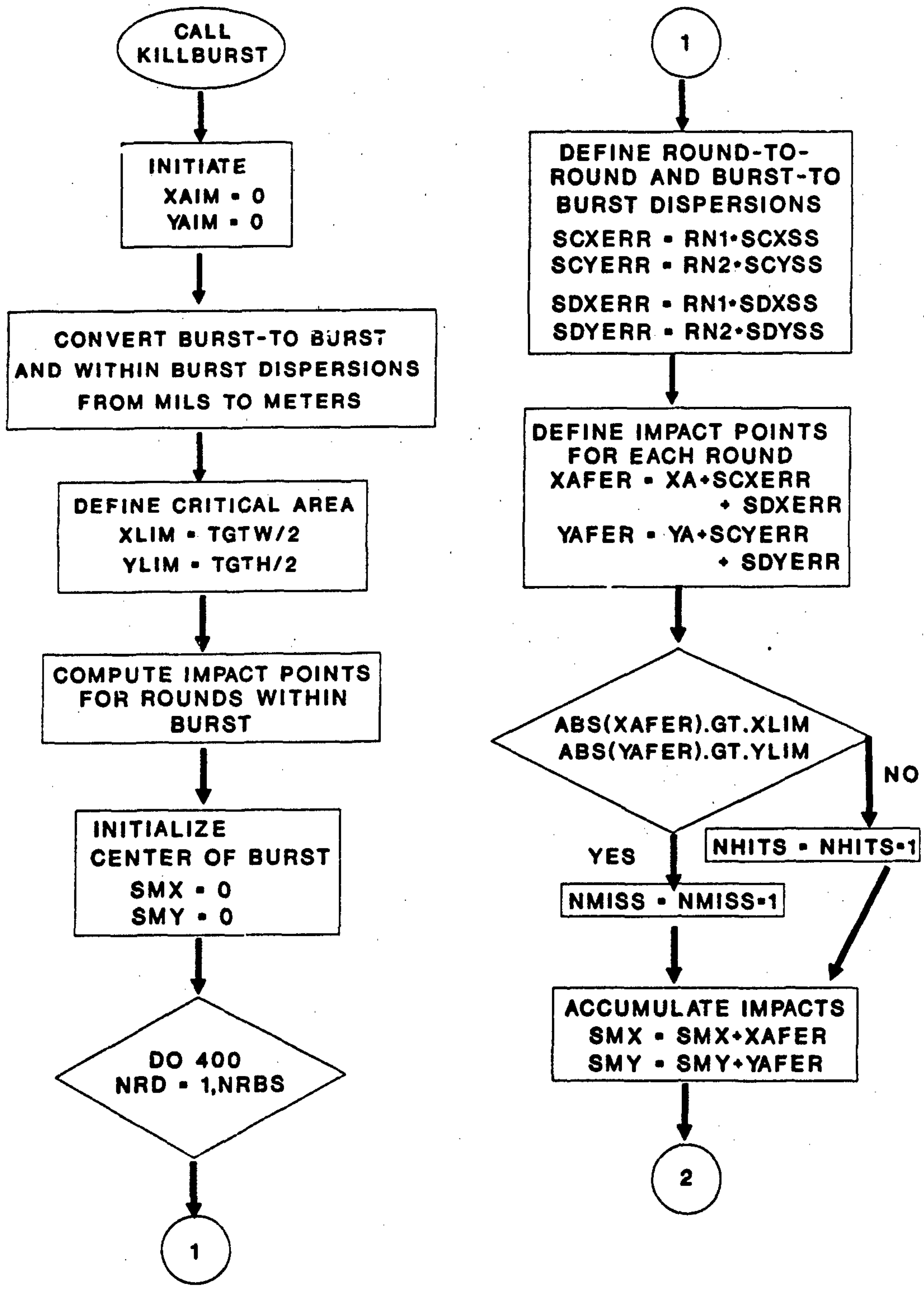

3
DETERMINE ANGLE OF FALL
NXR1 = INDEX
NXR2 = NXR1+1
AMMO ?
HEI-T
APDS-T
IPRJ = 1
IPRJ = 2
ANGLEF = ANGFAL(IPRJ,NXR1)
CONVERT ANGLE OF FALL FROM MILS TO RADIANS
ANGLER = PI*ANGLEF/3200
CALCULATE VERTICAL MISS DISTANCE ON TARGET PLANE
(+ = HIGH, - = LOW)
VMD = (INDEX*100-RANGE)*TAN(ANGLER)
4
4
ADD FIXED BIASES AND TOTAL DISPERSIONS FOR FIRST ROUND AND COMPUTE IMPACT POINT
XA = XAIM+FBHOR+RN1*DH
YA = YAIM+VMD+FBVER+RN2*DV
DETERMINE TARGET HIT
XMISSD = XA-XAIM
YMISSD = YA-YAIM
ABS(XMISSD).GT.XLIM
ABS(YMISSD).GT.YLIM
NO
YES
NHITS = NHITS+1
NMISS = NMISS+1
ADJUST BOT YAKIMA TEST DATA ALGORITHM
XA = (.4+RN1*.7)*XMISSD+XAIM
YA = (.4+RN2*.7)*YMISSD+YAIM
RETURN

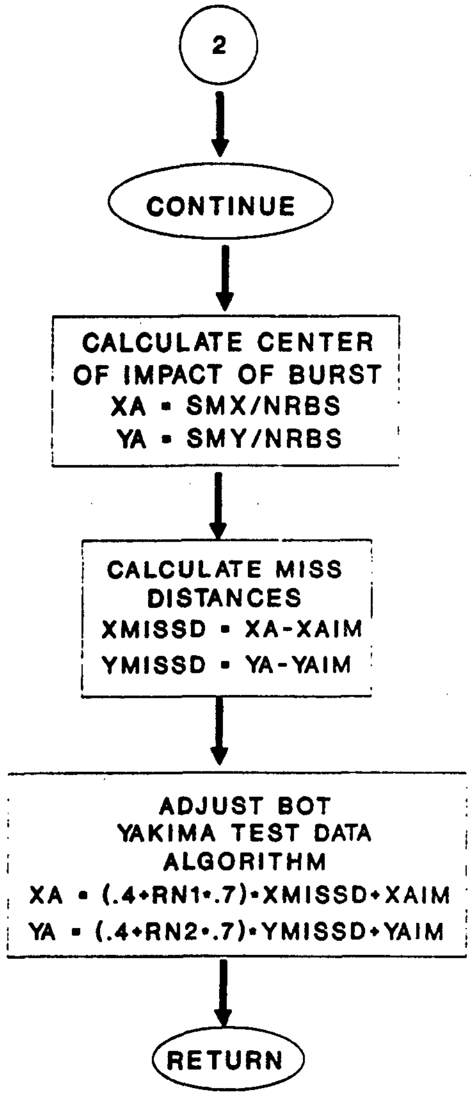

CALL RANGEIN
INITIATE
XAIM = 0
YAIM = 0
CONVERT DISPERSIONS FROM MILS TO METERS
DEFINE CRITICAL AREA
XLIM = TGTW/2
YLIM = TGTH/2
COMPUTE IMPACT POINT FOR SUBSEQUENT SINGLE ROUND
DEFINE ROUND-TO-ROUND DISPERSIONS
SDXERR = RN1*SDXZZ
SDYERR = RN2*SDYZZ
DEFINE IMPACT POINT FOR SECOND ROUND
XA = XA+SDXERR
YA = YA+SDYERR
1
1
CALCULATE MISS DISTANCES
XMISSD = XA-XAIM
YMISSD = YA-YAIM
ABS(XMISSD).GT.XLIM
ABS(YMISSD).GT.YLIM
NO
NHITS = NHITS+1
YES
NMISS = NMISS+1
ADJUST BOT YAKIMA TEST DATA ALGORITHM
XA = (.4+RN1*.7)*XMISSD+XAIM
YA = (.4+RN2*.7)*YMISSD+YAIM
RETURN


CALL FIRSTBURST
COMPUTE FIXED BIASES, TOTAL AND WITHIN BURST DISPERSIONS
CONVERT BIASES, FIRST RND, AND WITHIN BURST DISPERSIONS FROM MILS TO METERS
INITIATE XAIM = 0 YAIM = 0
DEFINE CRITICAL AREA XLIM = TGTW/2 YLIM = TGTH/2
COMPUTE RANGE ESTIMATE RGEST = RANGE*PRE*RN3+RANGE
MODE ?
PRECISION
DETERMINE INDEX RANGE INDEX = (AINT(RGEST/200))*2
2
BATTLESIGHT
1
1
EXTENDED ?
RGEST > 1400
INDEX = 16
RGEST <= 1400
INDEX = 12
2


3
DETERMINE ANGLE OF FALL
NXR1 = INDEX
NXR2 = NXR1+1
AMMO ?
HEI-T
APDS-T
IPRJ = 1
IPRJ = 2
ANGLEF = ANGFAL(IPRJ,NXR1)
CONVERT ANGLE OF FALL
FROM MILS TO RADIANS
ANGLER = PI*ANGLEF/3200
CALCULATE VERTICAL MISS
DISTANCE ON TARGET PLANE
(+ = HIGH, - = LOW)
VMD = (INDEX*100-RANGE)*
TAN(ANGLER)
4
4
ADD FIXED BIASES AND
TOTAL DISPERSIONS FOR
FIRST ROUND
XA = XAIM+FBHOR+RN1*DH
YA = YAIM+VMD+FBVER+RN2*DV
COMPUTE IMPACT POINTS
FOR ROUNDS WITHIN
BURST
INITIALIZE
CENTER OF BURST
SMX = 0
SMY = 0
DO 400
NRD = 1,NRBS
5


5
DEFINE ROUND-TO-ROUND AND BURST-TO BURST DISPERSIONS
SCXERR = RN1*SCXSS
SCYERR = RN2*SCYSS
SDXERR = RN1*SDXSS
SDYERR = RN2*SDYSS
DEFINE IMPACT POINTS FOR EACH ROUND
XAFER = XA+SCXERR + SDXERR
YAFER = YA+SCYERR + SDYERR
ABS(XAFER).GT.XLIM
ABS(YAFER).GT.YLIM
YES
NO
NMISS = NMISS+1
NHITS = NHITS+1
ACCUMULATE IMPACTS
SMX = SMX+XAFER
SMY = SMY+YAFER
6
6
400
CONTINUE
CALCULATE CENTER OF IMPACT OF BURST
XA = SMX/NRBS
YA = SMY/NRBS
CALCULATE MISS DISTANCES
XMISSD = XA-XAIM
YMISSD = YA-YAIM
ADJUST BOT
YAKIMA TEST DATA
ALGORITHM
XA = (.4+RN1*.7)*XMISSD+XAIM
YA = (.4+RN2*.7)*YMISSD+YAIM
RETURN


CALL KILLBURST
INITIATE
XAIM = 0
YAIM = 0
CONVERT BURST-TO BURST AND WITHIN BURST DISPERSIONS FROM MILS TO METERS
DEFINE CRITICAL AREA
XLIM = TGTW/2
YLIM = TGTH/2
COMPUTE IMPACT POINTS FOR ROUNDS WITHIN BURST
INITIALIZE CENTER OF BURST
SMX = 0
SMY = 0
DO 400
NRD = 1,NRBS
1
1
DEFINE ROUND-TO-ROUND AND BURST-TO BURST DISPERSIONS
SCXERR = RN1*SCXSS
SCYERR = RN2*SCYSS
SDXERR = RN1*SDXSS
SDYERR = RN2*SDYSS
DEFINE IMPACT POINTS FOR EACH ROUND
XAFER = XA+SCXERR + SDXERR
YAFER = YA+SCYERR + SDYERR
ABS(XAFER).GT.XLIM
ABS(YAFER).GT.YLIM
NO
YES
NHITS = NHITS+1
NMISS = NMISS+1
ACCUMULATE IMPACTS
SMX = SMX+XAFER
SMY = SMY+YAFER
2


2
CONTINUE
CALCULATE CENTER OF IMPACT OF BURST
XA = SMX/NRBS
YA = SMY/NRBS
CALCULATE MISS DISTANCES
XMISSD = XA-XAIM
YMISSD = YA-YAIM
ADJUST BOT YAKIMA TEST DATA ALGORITHM
XA = (.4+RN1*.7)*XMISSD+XAIM
YA = (.4+RN2*.7)*YMISSD+YAIM
RETURN

Appendix B: POINT TARGET ENGAGEMENT Simulation Model Computer Code

This appendix contains the SLAM II and FORTRAN computer code for the simulation model POINT TARGET ENGAGEMENT. The model has a SLAM II main program with seven FORTRAN subroutines.

```
GEN,RILEY,POINT TGT ENGAGEMENT,9/25/92,30,,,,,Y/1,72;
LIMITS,,13,50;
SEEDS,4367651(1),6121137(2),9375295(3);
NETWORK;
;  CREATE 100 TARGETS
      CREATE,5,,,100;
;
;  ATRIB(1)   - NUMBER OF ROUNDS IN FIRST BURST
;  ATRIB(2)   - NUMBER OF ROUNDS IN SECOND BURST
;  ATRIB(3)   - NUMBER OF ROUNDS IN THIRD BURST
;  ATRIB(4)   - NUMBER OF ROUNDS IN FOURTH BURST
;  ATRIB(5)   - MODE:  BATTLESIGHT OR PRECISION
;  ATRIB(6)   - RANGE TO TARGET
;  ATRIB(7)   - TARGET ASPECT (WIDTH)
;  ATRIB(8)   - LOCATION OF ROUND/BURST ON HORIZONTAL AXIS
;  ATRIB(9)   - LOCATION OF ROUND/BURST ON VERTICAL AXIS
;  ATRIB(10) - NUMBER OF HITS OF TARGET
;  ATRIB(11) - NUMBER OF MISSES OF TARGET
;  ATRIB(12) - TARGET KILL
;
      ASSIGN,ATRIB(1)=1.,
             ATRIB(2)=1.,
             ATRIB(3)=3.,
             ATRIB(4)=3.,
             ATRIB(5)=0.,
             ATRIB(6)=UNFRM(800.,1800.),
             ATRIB(7)=UNFRM(2.94,6.74),
             ATRIB(8)=0.,
             ATRIB(9)=0.,
             ATRIB(10)=0.,
             ATRIB(11)=0.,
             ATRIB(12)=0.;
      ACT;
      EVENT,2,1;    FIRE FIRST SENSING ROUND/BURST
;
      ACT/1,,ATRIB(10).GE.1.,K1;     BURST 1 HIT
      ACT;

B2    EVENT,3,1;    FIRE SUBSEQUENT SENSE ROUND/BURST
;
      ACT/2,,ATRIB(10).GE.3.AND.ATRIB(12).EQ.0,K2; B2 KILL
      ACT;

B3    EVENT,6,1;    FIRE SUBSEQUENT SENSE ROUND/BURST
;
      ACT/3,,ATRIB(10).GE.3.AND.ATRIB(12).EQ.0,K3; B3 KILL

      ACT;

B4    EVENT,7,1;    FIRE SUBSEQUENT SENSE ROUND/BURST
;
      ACT,,ATRIB(4).EQ.0.,STAT;
```

```
        ACT/4,,ATRIB(10).GE.3.AND.ATRIB(12).EQ.0,K4; B4 KILL
        ACT,,,STAT;
;
K1      GOON,1;
        ACT,,,B2;
K2      ASSIGN,ATRIB(12)=1; TARGET KILL ON SECOND ROUND/BURST
             ACT,,,B3;
K3      ASSIGN,ATRIB(12)=1; TARGET KILL ON THIRD BURST
        ACT,,,B4;
K4      ASSIGN,ATRIB(12)=1; TARGET KILL ON FOURTH BURST

STAT    COLCT,ATRIB(6),TARGET RANGE;
        COLCT,ATRIB(7),TARGET WIDTH;
        COLCT,ATRIB(10),NUMBER OF HITS;
        COLCT,ATRIB(11),NUMBER OF MISSES;
        COLCT,ATRIB(12),TARGET KILL;
        ACT,,ATRIB(12).EQ.0,TM;
        ACT;
        ASSIGN,ATRIB(13)=3;
        ASSIGN,ATRIB(10)=0;
        ASSIGN,ATRIB(11)=0;
        EVENT,8,1;
        ACT;
        COLCT,ATRIB(10),NUMBER OF HITS 3;
        ASSIGN,ATRIB(13)=4;
        ASSIGN,ATRIB(10)=0;
        ASSIGN,ATRIB(11)=0;
        EVENT,8,1;
        ACT;
        COLCT,ATRIB(10),NUMBER OF HITS 4;
        ASSIGN,ATRIB(13)=5;
        ASSIGN,ATRIB(10)=0;
        ASSIGN,ATRIB(11)=0;
        EVENT,8,1;
        ACT;
        COLCT,ATRIB(10),NUMBER OF HITS 5;
TM      TERM;
        END;
FIN;
```

```
*****************************************************************
*23456789112345678921234567893123456789412345678951234567896
*****************************************************************
*                       SLAM II FORTRAN SUBROUTINES
*****************************************************************
*                           PROGRAM MAIN
*****************************************************************
      PROGRAM MAIN
      DIMENSION NSET(10000)
      INCLUDE'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     +SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=10000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      CALL SLAM
      STOP
      END

*****************************************************************
*                       SUBROUTINE EVENT
*****************************************************************
      SUBROUTINE EVENT(I)
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     +SSL(100),TNEXT,TNOW,XX(100)
      COMMON /A/TGTH,PI,RN1,RN2,RN3,NRBS
      COMMON /B/SDXZ,SDYZ,SCXS,SCYS,SDXS,SDYS
      COMMON /C/XAIM,YAIM,ANGFAL(4,50),PRE,SPACE,PCT
      COMMON /D/XMISSD,YMISSD,VMD
      COMMON /BIAS/FBH,FBV,DISPH,DISPV
      REAL RANGE, MODE, TGTW, NHITS, NMISS, XA, YA
      EQUIVALENCE(RANGE,ATRIB(6)),(MODE,ATRIB(5)),
     +(TGTW,ATRIB(7)),(NHITS,ATRIB(10)),(NMISS,ATRIB(11)),
     +(XA,ATRIB(8)),(YA,ATRIB(9))
      RN1=RNORM(0.,1.,1)
      RN2=RNORM(0.,1.,2)
      RN3=RNORM(0.,1.,3)
      GO TO (1,2,3,4,5,6,7,8),I
1     RETURN
2     NRBS=ATRIB(1)
      CALL SENSE
      RETURN
3     NRBS=ATRIB(2)
      CALL RANGEIN
      RETURN
```

```
 4      NRBS=ATRIB(1)
        CALL FRSTBURST
        RETURN
 5      NRBS=ATRIB(2)
        CALL KILLBURST
        RETURN
 6      NRBS=ATRIB(3)
        CALL KILLBURST
        RETURN
 7      NRBS=ATRIB(4)
        CALL KILLBURST
        RETURN
 8      NRBS=ATRIB(13)
        CALL EFFECTS
        RETURN
        END

**************************************************************
        SUBROUTINE SENSE
**************************************************************
        INCLUDE 'SLAM$DIR:PARAM.INC'
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
       +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
       +SSL(100),TNEXT,TNOW,XX(100)
        COMMON /A/TGTH,PI,RN1,RN2,RN3,NRBS
        COMMON /B/SDXZ,SDYZ,SCXS,SCYS,SDXS,SDYS
        COMMON /C/XAIM,YAIM,ANGFAL(4,50),PRE,SPACE,PCT
        COMMON /D/XMISSD,YMISSD,VMD
        COMMON /BIAS/FBH,FBV,DISPH,DISPV
        REAL RANGE, MODE, TGTW, NHITS, NMISS, XA, YA
        EQUIVALENCE (RANGE,ATRIB(6)),(MODE,ATRIB(5)),
       +(TGTW,ATRIB(7)),(NHITS,ATRIB(10)),(NMISS,ATRIB(11)),
       +(XA,ATRIB(8)),(YA,ATRIB(9))

*   25mm api-t nov 83 data

data(angfal(1,j),j=1,50)/.283,.573,.873,1.18,1.50,1.84,2.18,
2.54,2.91,3.30,3.70,4.11,4.54,4.99,5.45,5.94,6.44,6.96,7.51,
8.07,8.67,9.28,9.93,10.6,11.3,12.04,12.81,13.61,14.46,15.35,
16.30,17.26,18.29,19.38,20.53,21.74,23.01,24.36,25.78,27.28,
28.86,30.54,32.32,34.20,36.19,38.31,40.56,42.95,45.49,48.19/

*   25mm heit 26 nov 83 data

data(angfal(2,j),j=1,50)/.44,.94,1.52,2.18,2.95,3.83,4.85,6.
03,7.41,9.01,10.88,13.07,15.63,18.64,22.16,26.31,31.19,
36.88,43.35,50.53,58.36,66.77,75.70,85.11,95.01,105.42,
116.34,127.82,139.87,152.54,165.84,179.82,194.5,209.9,
226.06,243.02,260.78,279.38,298.85,319.19,340.43,362.60,
385.69,409.72,434.70,460.63,487.51,515.34,544.12,573.84/
```

```
*   FIRST SINGLE SENSE ROUND
*   ASSUME MUZZLE HEIGHT = HEIGHT OF ORIGINAL AIMPOINT

C   THE ORIGINAL AIMPOINT IS THE CENTER OF THE TARGET (0,0)=
C   (XAIM,YAIM) WITH A FIRST ROUND RANGE-IN FIXED BIAS OF
C   (FBH,FBV)
C   AND A TOTAL FIRST ROUND DISPERSION OF (DISPH,DISPV).
C   DISPERSIONS AND BAISES IN MILS
C   SDXZ,SDYZ - RANGIN DISP I.E. SINGLE SHOT DISP;
       SDXZ=.46
       SDYZ=.48
C SDXS,SDYS - FIRE FOR EFFECT DISP BURST-TO-BURST;
       SDXS=.28
       SDYS=.33
C SCXS,SCYX FIRE FOR EFFECT DISP WITH-IN BURST DISP
       SCXS=.46
       SCYS=.38

       XAIM=0.
       YAIM=0.
       TGTH=2.2
       PI=3.14159265359
       IPRJ=1

*   COMPUTE FIXED BIAS AND TOTAL DISPERSION AT TGT RANGE

       FBH=-1.78346+0.00227*RANGE-6.453E-07*RANGE**2
       FBV=-1.17336+0.00152*RANGE-4.424E-07*RANGE**2
       DISPH=1.31464-4.955E-04*RANGE+2.033E-07*RANGE**2
       DISPV=1.20870-5.813E-04*RANGE+3.712E-07*RANGE**2

*   CONVERT DISPERSIONS TO METERS
       SDXZZ=RANGE*PI*SDXZ/3200.
       SDYZZ=RANGE*PI*SDYZ/3200.
       FBHOR=RANGE*PI*FBH/3200.
       FBVER=RANGE*PI*FBV/3200
       DH=RANGE*PI*DISPH/3200.
       DV=RANGE*PI*DISPV/3200.

*    TARGET CRITICAL AREA
       XLIM=TGTW/2.
       YLIM=TGTH/2.

*    RANGE ESTIMATION ERROR IS 17%
*    INDEX RANGE IS CLOSEST 200M INCREMENT IN PRECISION MODE
*    INDEX RANGE IS 12 FOR RGEST LESS THAN 1400M IN
*    BATTLESIGHT  MODE
*    INDEX RANGE IS 16 FOR RGEST GREATER THAN 1400M IN
*    BATTLESIGHT MODE
```

```
      PRE = .17
      RGEST=RANGE*PRE*RN3+RANGE
      IF(MODE.EQ.0)GO TO 20
      INDEX=(AINT(RGEST/200))*2
      GO TO 25
20    IF(RGEST.LE.1400)INDEX=12
      IF(RGEST.GT.1400)INDEX=16

*   CALCULATE ANGLE OF FALL TO INDEXED RANGE
25    NXR1=INDEX

      ANGLEF=ANGFAL(IPRJ,NXR1)

*   CONVERT ANGLE OF FALL FROM MILS TO RADIANS
      ANGLER=PI*ANGLEF/3200

*   VERTICAL MISS DISTANCE ON TARGET PLANE
*   (+ = HIGH, - = LOW)

      VMD=(INDEX*100-RANGE)*TAN(ANGLER)

*   ADD FIXED BIASES AND TOTAL DISPERSIONS FOR FIRST ROUND
*   COMPUTE IMPACT POINT
      XA=XAIM+FBHOR+RN1*DH
      YA=YAIM+VMD+FBVER+RN2*DV

      XMISSD=XA-XAIM
      YMISSD=YA-YAIM
      IF(ABS(XMISSD).GT.XLIM)GO TO 130
      IF(ABS(YMISSD).GT.YLIM)GO TO 130

*   RANGE IN COMPLETE
      NHITS=NHITS+1
      GO TO 135
130   NMISS=NMISS+1

*   YAKIMA TEST DATA ADJUSTMENT ALGORITHM
135   XA=(.4+RN1*.7)*XMISSD+XAIM
      YA=(.4+RN2*.7)*YMISSD+YAIM
      RETURN
      END
```

```
***********************************************************************
      SUBROUTINE RANGEIN
***********************************************************************
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     +SSL(100),TNEXT,TNOW,XX(100)
      COMMON /A/TGTH,PI,RN1,RN2,RN3,NRBS
      COMMON /B/SDXZ,SDYZ,SCXS,SCYS,SDXS,SDYS
      COMMON /C/XAIM,YAIM,ANGFAL(4,50),PRE,SPACE,PCT
      COMMON /D/XMISSD,YMISSD,VMD
      COMMON /BIAS/FBH,FBV,DISPH,DISPV
      REAL RANGE, MODE, TGTW, NHITS, NMISS, XA, YA
      EQUIVALENCE (RANGE,ATRIB(6)),(MODE,ATRIB(5)),
     +(TGTW,ATRIB(7)),(NHITS,ATRIB(10)),(NMISS,ATRIB(11)),
     +(XA,ATRIB(8)),(YA,ATRIB(9))


*   DISPERSIONS AND BIASES IN MILS
*   SDXZ,SDYZ - SINGLE SHOT DISPERSION
      SDXZ=.46
      SDYZ=.48

      XAIM=0.
      YAIM=0.
      TGTH=2.2
      PI=3.14159265359

*    TARGET CRITICAL AREA
      XLIM=TGTW/2.
      YLIM=TGTH/2.

*   CONVERT DISPERSIONS TO METERS
      SDXZZ=RANGE*PI*SDXZ/3200.
      SDYZZ=RANGE*PI*SDYZ/3200.

      SDXERR=RN1*SDXZZ
      SDYERR=RN2*SDYZZ

*    COMPUTE IMPACT POINT OF SUBSEQUENT SINGLE ROUND
      XA=XA+SDXERR
      YA=YA+SDYERR

      XMISSD=XA-XAIM
      YMISSD=YA-YAIM
      IF(ABS(XMISSD).GT.XLIM)GO TO 230
      IF(ABS(YMISSD).GT.YLIM)GO TO 230

*    RANGE IN COMPLETE
      NHITS=NHITS+1
      GO TO 235
230   NMISS=NMISS+1
```

```
*   YAKIMA TEST DATA ADJUSTMENT ALGORITHM
235   XA=(.4+RN1*.7)*XMISSD+XAIM
      YA=(.4+RN2*.7)*YMISSD+YAIM
      RETURN
      END


*****************************************************************
      SUBROUTINE FRSTBURST
*****************************************************************
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     +SSL(100),TNEXT,TNOW,XX(100)
      COMMON /A/TGTH,PI,RN1,RN2,RN3,NRBS
      COMMON /B/SDXZ,SDYZ,SCXS,SCYS,SDXS,SDYS
      COMMON /C/XAIM,YAIM,ANGFAL(4,50),PRE,SPACE,PCT
      COMMON /D/XMISSD,YMISSD,VMD
      COMMON /BIAS/FBH,FBV,DISPH,DISPV
      REAL RANGE, MODE, TGTW, NHITS, NMISS, XA, YA
      EQUIVALENCE (RANGE,ATRIB(6)),(MODE,ATRIB(5)),
     +(TGTW,ATRIB(7)),(NHITS,ATRIB(10)),(NMISS,ATRIB(11)),
     +(XA,ATRIB(8)),(YA,ATRIB(9))
*  25mm api-t nov 83 data

data(angfal(1,j),j=1,50)/.283,.573,.873,1.18,1.50,1.84,2.18,
2.54,2.91,3.30,3.70,4.11,4.54,4.99,5.45,5.94,6.44,6.96,7.51,
8.07,8.67,9.28,9.93,10.6,11.3,12.04,12.81,13.61,14.46,15.35,
16.30,17.26,18.29,19.38,20.53,21.74,23.01,24.36,25.78,27.28,
28.86,30.54,32.32,34.20,36.19,38.31,40.56,42.95,45.49,48.19/

*  25mm heit 26 nov 83 data

data(angfal(2,j),j=1,50)/.44,.94,1.52,2.18,2.95,3.83,4.85,6.
03,7.41,9.01,10.88,13.07,15.63,18.64,22.16,26.31,31.19,
36.88,43.35,50.53,58.36,66.77,75.70,85.11,95.01,105.42,
116.34,127.82,139.87,152.54,165.84,179.82,194.5,209.9,
226.06,243.02,260.78,279.38,298.85,319.19,340.43,362.60,
385.69,409.72,434.70,460.63,487.51,515.34,544.12,573.84/

*  FIRST BURST WITHOUT RANGE IN
*  ASSUME MUZZLE HEIGHT = HEIGHT OF ORIGINAL AIMPOINT

C  THE ORIGINAL AIMPOINT IS THE CENTER OF THE TARGET (0,0)=
C  (XAIM,YAIM) WITH A FIRST ROUND RANGE-IN FIXED BIAS OF
C  (FBH,FBV)
C  AND A TOTAL FIRST ROUND DISPERSION OF (DISPH,DISPV).
C  DISPERSIONS AND BIASES IN MILS
C  SDXS,SDYS - FIRE FOR EFFECT DISP BURST-TO-BURST;
     SDXS=.28
     SDYS=.33
```

```
C  SCXS,SCYS FIRE FOR EFFECT DISP WITH-IN BURST DISP
      SCXS=.46
      SCYS=.38

      XAIM=0.
      YAIM=0.
      TGTH=2.2
      PI=3.14159265359
      IPRJ=1

*  COMPUTE FIXED BIAS AND TOTAL DISPERSION AT TGT RANGE

      FBH=-1.78346+0.00227*RANGE-6.453E-07*RANGE**2
      FBV=-1.17336+0.00152*RANGE-4.424E-07*RANGE**2
      DISPH=1.31464-4.955E-04*RANGE+2.033E-07*RANGE**2
      DISPV=1.20870-5.813E-04*RANGE+3.712E-07*RANGE**2

*  CONVERT DISPERSIONS TO METERS
      FBHOR=RANGE*PI*FBH/3200.
      FBVER=RANGE*PI*FBV/3200
      DH=RANGE*PI*DISPH/3200.
      DV=RANGE*PI*DISPV/3200.
      SCXSS=SCXS*PI*RANGE/3200.
      SCYSS=SCYS*PI*RANGE/3200.
      SDXSS=SDXS*PI*RANGE/3200.
      SDYSS=SDYS*PI*RANGE/3200.

*   TARGET CRITICAL AREA

      XLIM=TGTW/2.
      YLIM=TGTH/2.

*   RANGE ESTIMATION ERROR IS 17%
*   INDEX RANGE IS CLOSEST 200M INCREMENT IN PRECISION MODE
*   INDEX RANGE IS 12 FOR RGEST LESS THAN 1400M IN
*   BATTLESIGHT MODE
*   INDEX RANGE IS 16 FOR RGEST GREATER THAN 1400M IN
*   BATTLESIGHT MODE

      PRE = .17
      RGEST=RANGE*PRE*RN3+RANGE
      IF(MODE.EQ.0)GO TO 50
      INDEX=(AINT(RGEST/200))*2
      GO TO 55
50    IF(RGEST.LE.1400)INDEX=12
      IF(RGEST.GT.1400)INDEX=16


*   CALCULATE ANGLE OF FALL TO INDEXED RANGE
55    NXR1=INDEX

      ANGLEF=ANGFAL(IPRJ,NXR1)
```

```
*    CONVERT ANGLE OF FALL FROM MILS TO RADIANS
       ANGLER=PI*ANGLEF/3200

*    VERTICAL MISS DISTANCE ON TARGET PLANE
*    (+ = HIGH, - = LOW)

       VMD=(INDEX*100-RANGE)*TAN(ANGLER)

*    ADD FIXED BIASES AND TOTAL DISPERSIONS FOR FIRST ROUND
       XA=XAIM+FBHOR+RN1*DH
       YA=YAIM+VMD+FBVER+RN2*DV

*    COMPUTE IMPACT POINTS FOR ROUNDS WITHIN BURST
       SMX=0
       SMY=0
       DO 400 NRD=1,NRBS
       SCXERR=RN1*SCXSS
       SCYERR=RN2*SCYSS
       SDXERR=RN1*SDXSS
       SDYERR=RN2*SDYSS
       XAFER=XA+SCXERR+SDXERR
       YAFER=YA+SCYERR+SDYERR

       IF(ABS(XAFER).GT.XLIM)GOTO 300
       IF(ABS(YAFER).GT.YLIM)GOTO 300

*    RANGE IN COMPLETE
       NHITS=NHITS+1
       GOTO 310
300    NMISS=NMISS+1
310    SMX=SMX+XAFER
       SMY=SMY+YAFER
400    CONTINUE
       XA=SMX/NRBS
       YA=SMY/NRBS

       XMISSD=XA-XAIM
       YMISSD=YA-YAIM

*    YAKIMA TEST DATA ADJUSTMENT ALGORITHM
       XA=(.4+RN1*.7)*XMISSD+XAIM
       YA=(.4+RN2*.7)*YMISSD+YAIM
       RETURN
       END
```

```
*****************************************************************
      SUBROUTINE KILLBURST
*****************************************************************
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     +SSL(100),TNEXT,TNOW,XX(100)
      COMMON /A/TGTH,PI,RN1,RN2,RN3,NRBS
      COMMON /B/SDXZ,SDYZ,SCXS,SCYS,SDXS,SDYS
      COMMON /C/XAIM,YAIM,ANGFAL(4,50),PRE,SPACE,PCT
      COMMON /D/XMISSD,YMISSD,VMD
      COMMON /BIAS/FBH,FBV,DISPH,DISPV
      REAL RANGE, MODE, TGTW, NHITS, NMISS, XA, YA
      EQUIVALENCE (RANGE,ATRIB(6)),(MODE,ATRIB(5)),
     +(TGTW,ATRIB(7)),(NHITS,ATRIB(10)),(NMISS,ATRIB(11)),
     +(XA,ATRIB(8)),(YA,ATRIB(9))


*   SUBSEQUENT KILLING BURSTS AFTER INITIAL SENSING
*   ROUND/BURST

C   DISPERSIONS AND BIASES IN MILS
C   SDXS,SDYS - FIRE FOR EFFECT DISP BURST-TO-BURST;
      SDXS=.28
      SDYS=.33
C   SCXS,SCYS FIRE FOR EFFECT DISP WITH-IN BURST DISP
      SCXS=.46
      SCYS=.38

      XAIM=0.
      YAIM=0.
      TGTH=2.2
      PI=3.14159265359

*  CONVERT DISPERSIONS TC METERS
      SCXSS=SCXS*PI*RANGE/3200.
      SCYSS=SCYS*PI*RANGE/3200.
      SDXSS=SDXS*PI*RANGE/3200.
      SDYSS=SDYS*PI*RANGE/3200.

*   TARGET CRITICAL AREA
      XLIM=TGTW/2.
      YLIM=TGTH/2.

*   COMPUTE IMPACT POINTS FOR ROUNDS WITHIN BURST
      SMX=0
      SMY=0
      DO 600 NRD=1,NRBS
      SCXERR=RN1*SCXSS
      SCYERR=RN2*SCYSS
      SDXERR=RN1*SDXSS
      SDYERR=RN2*SDYSS
```

```
      XAFER=XA+SCXERR+SDXERR
      YAFER=YA+SCYERR+SDYERR
      IF(ABS(XAFER).GT.XLIM)GOTO 500
      IF(ABS(YAFER).GT.YLIM)GOTO 500

*    RANGE IN COMPLETE
      NHITS=NHITS+1
      GOTO 510
500   NMISS=NMISS+1
510   SMX=SMX+XAFER
      SMY=SMY+YAFER
600   CONTINUE
      XA=SMX/NRBS
      YA=SMY/NRBS

      XMISSD=XA-XAIM
      YMISSD=YA-YAIM

*    YAKIMA TEST DATA ADJUSTMENT ALGORITHM
      XA=(.4+RN1*.7)*XMISSD+XAIM
      YA=(.4+RN2*.7)*YMISSD+YAIM
      RETURN
      END

************************************************************
      SUBROUTINE EFFECTS
************************************************************
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     +MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     +SSL(100),TNEXT,TNOW,XX(100)
      COMMON /A/TGTH,PI,RN1,RN2,RN3,NRBS
      COMMON /B/SDXZ,SDYZ,SCXS,SCYS,SDXS,SDYS
      COMMON /C/XAIM,YAIM,ANGFAL(4,50),PRE,SPACE,PCT
      COMMON /D/XMISSD,YMISSD,VMD
      COMMON /BIAS/FBH,FBV,DISPH,DISPV
      REAL RANGE, MODE, TGTW, NHITS, NMISS, XA, YA
      INTEGER J,N
      EQUIVALENCE (RANGE,ATRIB(6)),(MODE,ATRIB(5)),
     +(TGTW,ATRIB(7)),(NHITS,ATRIB(10)),(NMISS,ATRIB(11)),
     +(XA,ATRIB(8)),(YA,ATRIB(9))

*    SUBSEQUENT KILLING BURSTS AFTER INITIAL EIGHT ROUND
*    ENGAGEMENT

C    DISPERSIONS AND BIASES IN MILS
C    SDXS,SDYS - FIRE FOR EFFECT DISP BURST-TO-BURST;
      SDXS=.28
      SDYS=.33
C    SCXS,SCYS FIRE FOR EFFECT DISP WITH-IN BURST DISP
      SCXS=.46
      SCYS=.38
```

```
      XAIM=0.
      YAIM=0.
      TGTH=2.2
      PI=3.14159265359

*   CONVERT DISPERSIONS TO METERS
      SCXSS=SCXS*PI*RANGE/3200.
      SCYSS=SCYS*PI*RANGE/3200.
      SDXSS=SDXS*PI*RANGE/3200.
      SDYSS=SDYS*PI*RANGE/3200.

*   TARGET CRITICAL AREA
      XLIM=TGTW/2.
      YLIM=TGTH/2.

*   DETERMINE NUMBER OF BURSTS TO FIRE
      IF(NRBS.EQ.3)THEN
      N=20
      ELSE IF(NRBS.EQ.4)THEN
      N=15
      ELSE IF(NRBS.EQ.5)THEN
      N=12
      END IF

*   LOCATION OF INITIAL ESTIMATED IMPACT POINT

      XA1=XA
      YA1=YA

*   FIRE APPROPRIATE NUMBER OF BURSTS
      DO 700 J=1,N

*   COMPUTE IMPACT POINTS FOR ROUNDS WITHIN BURST
      SMX=0
      SMY=0
      DO 600 NRD=1,NRBS
      SCXERR=RN1*SCXSS
      SCYERR=RN2*SCYSS
      SDXERR=RN1*SDXSS
      SDYERR=RN2*SDYSS
      XAFER=XA1+SCXERR+SDXERR
      YAFER=YA1+SCYERR+SDYERR
      IF(ABS(XAFER).GT.XLIM)GOTO 500
      IF(ABS(YAFER).GT.YLIM)GOTO 500

      NHITS=NHITS+1
      GOTO 510
500   NMISS=NMISS+1
510   SMX=SMX+XAFER
      SMY=SMY+YAFER
600   CONTINUE
```

```
      XA1=SMX/NRBS
      YA1=SMY/NRBS

      XMISSD=XA1-XAIM
      YMISSD=YA1-YAIM

*    YAKIMA TEST DATA ADJUSTMENT ALGORITHM
      XA1=(.4+RN1*.7)*XMISSD+XAIM
      YA1=(.4+RN2*.7)*YMISSD+YAIM

700   CONTINUE
      RETURN
      END
```

Appendix C: Fixed Bias and Random Dispersion Regression Equations

This appendix provides the derivation of the regression equations for fixed bias and total dispersions used in POINT TARGET ENGAGEMENT. The data are results from the first round probability model PH1 for 100 meter increments between ranges of 200 and 2000 meters. Since the targets in POINT TARGET ENGAGEMENT are generated at random ranges between 800 and 1800 meters, the regression equations are used in the SENSE and FRSTBURST sub-routines to predict appropriate estimates for bias and dispersion.

A.1 Data: Results from PH1 (31:1-2)

CASE	RG	RG2	FBH	FBV
1	400.00	160000.0	-1.1387	-0.7468
2	500.00	250000.0	-0.8045	-0.5228
3	600.00	360000.0	-0.5800	-0.3734
4	700.00	490000.0	-0.4182	-0.2667
5	800.00	640000.0	-0.2955	-0.1867
6	900.00	810000.0	-0.1989	-0.1245
7	1000.0	1000000.0	-0.1205	-0.0747
8	1100.0	1210000.0	-0.0553	-0.0339
9	1200.0	1440000.0	0.0000	0.0000
10	1200.0	1440000.0	0.0000	0.0000
11	1300.0	1690000.0	0.0477	0.0287
12	1400.0	1960000.0	0.0895	0.0533
13	1500.0	2250000.0	0.1266	0.0747
14	1600.0	2560000.0	0.1599	0.0933
15	1700.0	2890000.0	0.1901	0.1098
16	1800.0	3240000.0	0.2178	0.1245
17	1900.0	3610000.0	0.2433	0.1376
18	2000.0	4000000.0	0.2670	0.1494

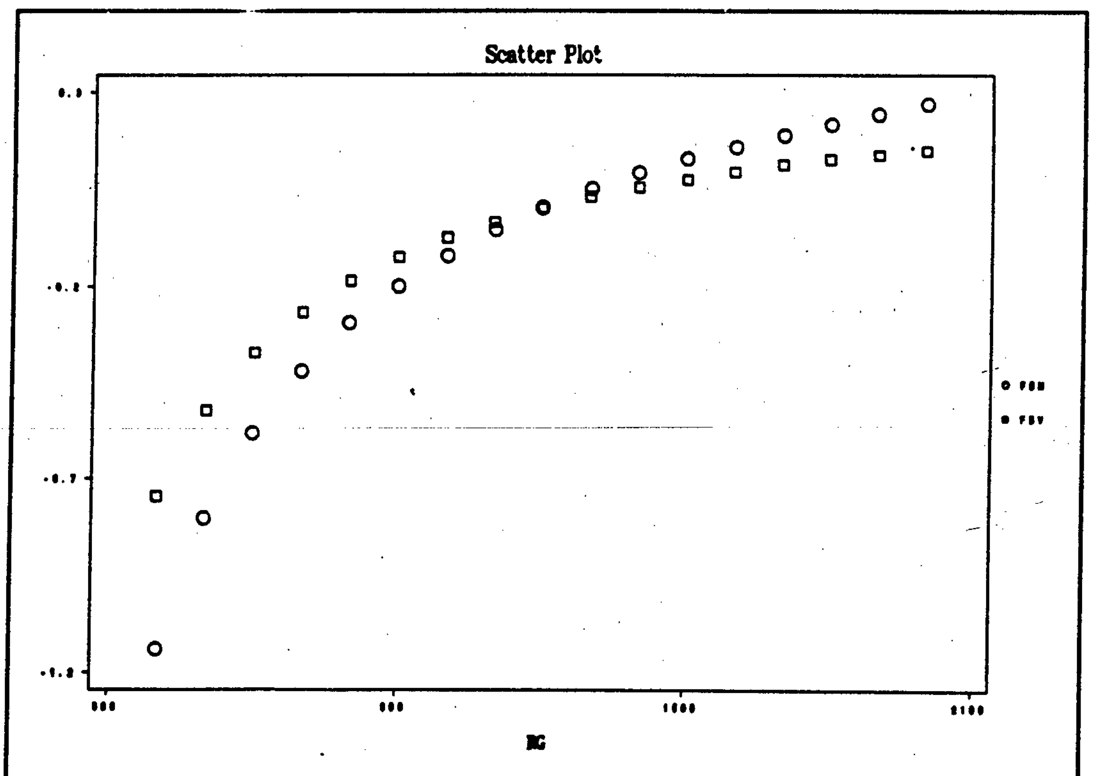


Figure C1. Scatter Plot of Fixed Bias Data

It is apparent from the scatter plot that the regression equation should include a quadratic term. Therefore:

A.2 Unweighted Least Squares Linear Regression of Fixed Bias Horizontal

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	-1.78346	0.09918	-17.98	0.0000
RG	0.00227	1.800E-04	12.65	0.0000
RG2	-6.453E-07	7.370E-08	-8.76	0.0000

R-SQUARED = 0.9738 RESID. MEAN SQUARE (MSE) = 0.00450
ADJUSTED R-SQUARED = 0.9703 STANDARD DEVIATION = 0.06712

SOURCE	DF	SS	MS	F	P
REGRESSION	2	2.51176	1.25588	278.70	0.0000
RESIDUAL	15	0.06759	0.00450		
TOTAL	17	2.57935			

A.3 Unweighted Least Squares Linear Regression of Fixed Bias Vertical

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	-1.17336	0.06738	-17.41	0.0000
RG	0.00152	1.223E-04	12.43	0.0000
RG2	-4.424E-07	5.007E-08	-8.84	0.0000

R-SQUARED = 0.9703 RESID. MEAN SQUARE (MSE) = 0.00208
ADJUSTED R-SQUARED = 0.9663 STANDARD DEVIATION = 0.04560

SOURCE	DF	SS	MS	F	P
REGRESSION	2	1.01934	0.50967	245.07	0.0000
RESIDUAL	15	0.03119	0.00208		
TOTAL	17	1.05054			

A.4 *Data: Results from PH1* (31:1-2)

CASE	RG	RG2	TDH	TDV
1	400.00	160000.0	1.2121	1.1081
2	500.00	250000.0	1.1190	1.0137
3	600.00	360000.0	1.0670	0.9673
4	700.00	490000.0	1.0369	0.9485
5	800.00	640000.0	1.0198	0.9477
6	900.00	810000.0	1.0112	0.9596
7	1000.0	1000000.0	1.0084	0.9815
8	1100.0	1210000.0	1.0100	1.0113
9	1200.0	1440000.0	1.0150	1.0479
10	1300.0	1690000.0	1.0229	1.0906
11	1400.0	1960000.0	1.0332	1.1389
12	1500.0	2250000.0	1.0456	1.1922
13	1600.0	2560000.0	1.0601	1.2505
14	1700.0	2890000.0	1.0764	1.3135
15	1800.0	3240000.0	1.0945	1.3810
16	1900.0	3610000.0	1.1142	1.4531
17	2000.0	4000000.0	1.1356	1.5297
18	2100.0	4410000.0	1.1585	1.6108
19	2200.0	4840000.0	1.1830	1.6966

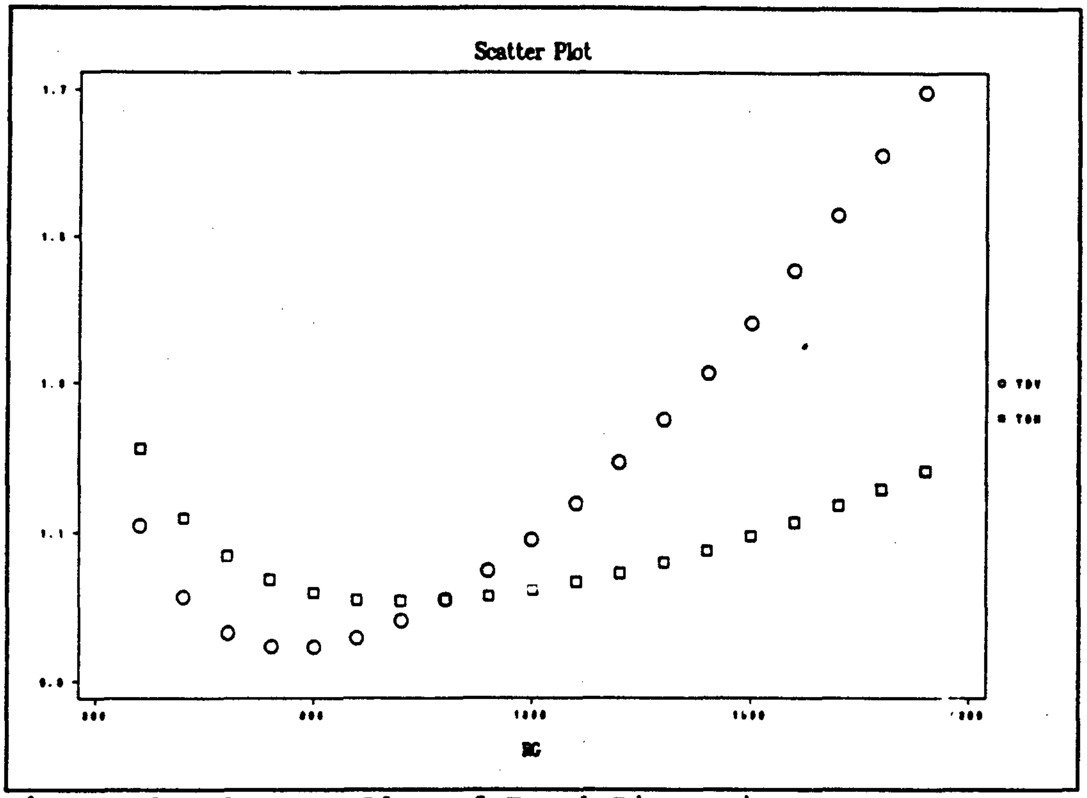


Figure C2. Scatter Plot of Total Dispersion Data

It is also apparent from the scatter plots of total dispersions that the regression equations should include a quadratic term. Therefore:

A.5 Unweighted Least Squares Linear Regression of Total Dispersion Horizontal

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	1.31464	0.03188	41.23	0.0000
RG	-4.955E-04	5.438E-05	-9.11	0.0000
RG2	2.033E-07	2.056E-08	9.89	0.0000

R-SQUARED = 0.8715 RESID. MEAN SQUARE (MSE) = 5.733E-04
ADJUSTED R-SQUARED = 0.8555 STANDARD DEVIATION = 0.02394

SOURCE	DF	SS	MS	F	P
REGRESSION	2	0.06222	0.03111	54.27	0.0000
RESIDUAL	16	0.00917	5.733E-04		
TOTAL	18	0.07140			

A.6 Unweighted Least Squares Linear Regression of Total Dispersion Vertical

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	1.20870	0.03716	32.52	0.0000
RG	-5.813E-04	6.339E-05	-9.17	0.0000
RG2	3.712E-07	2.396E-08	15.49	0.0000

R-SQUARED = 0.9880 RESID. MEAN SQUARE (MSE) = 7.790E-04
ADJUSTED R-SQUARED = 0.9865 STANDARD DEVIATION = 0.02791

SOURCE	DF	SS	MS	F	P
REGRESSION	2	1.02680	0.51340	659.07	0.0000
RESIDUAL	16	0.01246	7.790E-04		
TOTAL	18	1.03926			

Appendix D: Analysis of Shotgun Model Assumption

This appendix contains an auto-correlation analysis of five round burst impact points. The shotgun or two-distribution model is based on the assumption of constant correlation between rounds within bursts. Analysis of variance, time series plots and autocorrelation plots are used to confirm this assumption for the M242 Automatic Gun firing APDS-T ammunition. Live fire data was provided by Ground Warfare Division, US Army Material Systems Analysis Activity (AMSAA). The analysis leads to the conclusion that the assumption of constant correlation is appropriate.

A.1 Data Information

APDS-T Data File: Virtual Vertical and Horizontal Target Accuracy Firing

Date Fired: 18 May 1992

Range (M): 999.7

Vehicle: M2A2 BFV

Firing mode: Low rate, Five Round Bursts, Stationary, Gunner, Day Sight, Production Barrel

A.2 One-Way ANOVA for Vertical Impact Coordinates by Number of Round (TRT)

SOURCE	DF	SS	MS	F	P
BETWEEN	4	4.63036	1.15759	3.01	0.0230
WITHIN	75	28.8142	0.38418		
TOTAL	79	33.4445			

TUKEY (HSD) Pairwise Comparisons of Means of Y by Trt

TRT	MEAN	HOMOGENEOUS GROUPS
3	0.1437	I
2	-0.4031	I I
1	-0.4483	I I
5	-0.4792	.. I
4	-0.4830	.. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL Q VALUE	3.953	REJECTION LEVEL	0.050
CRITICAL VALUE	0.6126		
STANDARD ERROR	0.2191		

The ANOVA results show that the mean vertical impact point coordinates are not all equal, however, the groupings indicated by the Tukey method of multiple comparisons display no sequential pattern that would lead to the conclusion that the rounds are correlated.

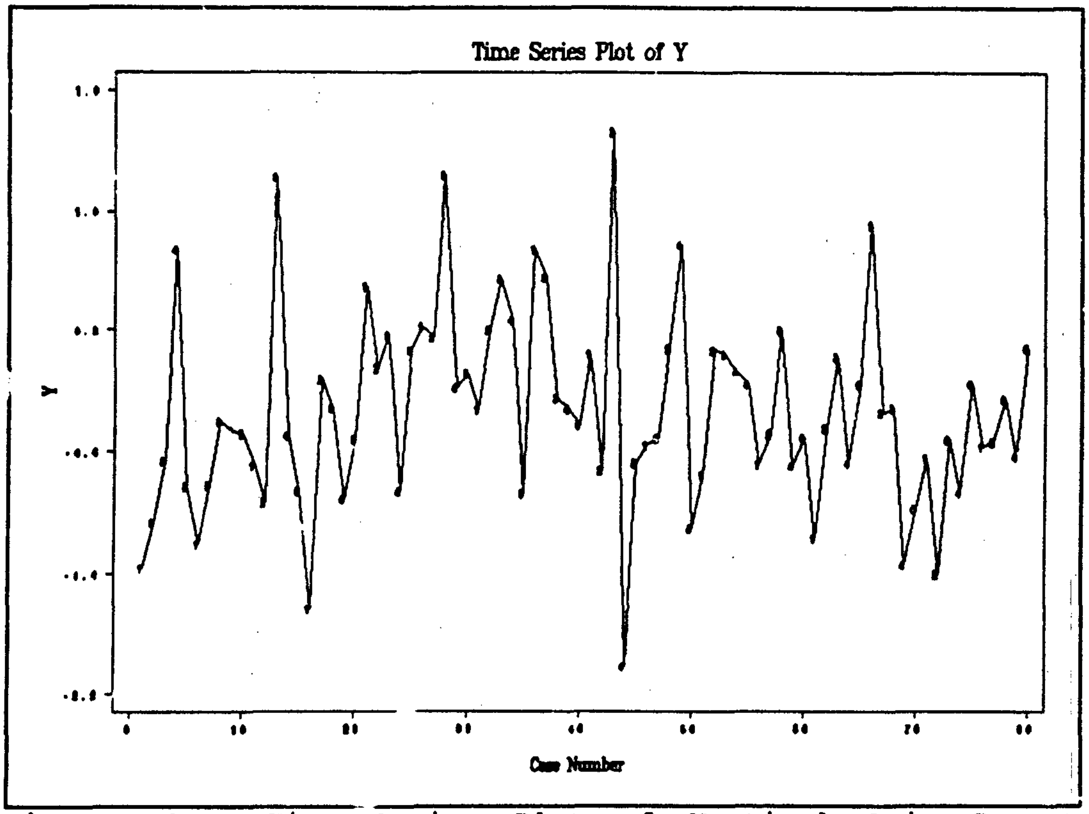
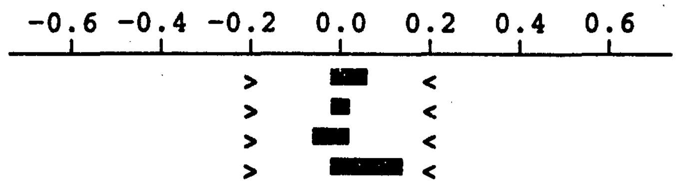


Figure D1. Time Series Plot of Vertical Axis Impact Coordinates

The time series plot reveals no systematic pattern to indicate any strong autocorrelation of impact points.

A.3 Autocorrelation Plot for Y

LAG	CORR.
1	0.028
2	0.010
3	−0.027
4	0.137



MEAN OF THE SERIES	−0.33400
STD. DEV. OF SERIES	0.64657
NUMBER OF CASES	80

There appears to be negligible correlation between vertical coordinates of the round-to-round impact points, certainly nothing that would disprove the shotgun model's assumption of constant correlation.

A.4 One-Way ANOVA for horizontal impact point coordinates by Number of Round (TRT)

SOURCE	DF	SS	MS	F	P
BETWEEN	4	0.49011	0.12252	0.17	0.9510
WITHIN	75	54.3473	0.72463		
TOTAL	79	54.8374			

TRT	MEAN	SAMPLE SIZE	GROUP STD DEV
1	0.8186	16	0.6858
2	0.9763	16	0.6950
3	0.7914	16	1.0054
4	0.7855	16	0.8780
5	0.7543	16	0.9422
TOTAL	0.8252	80	0.8512

The ANOVA results show that there is no difference in the mean horizontal impact point coordinates between the individual rounds of the five round burst.

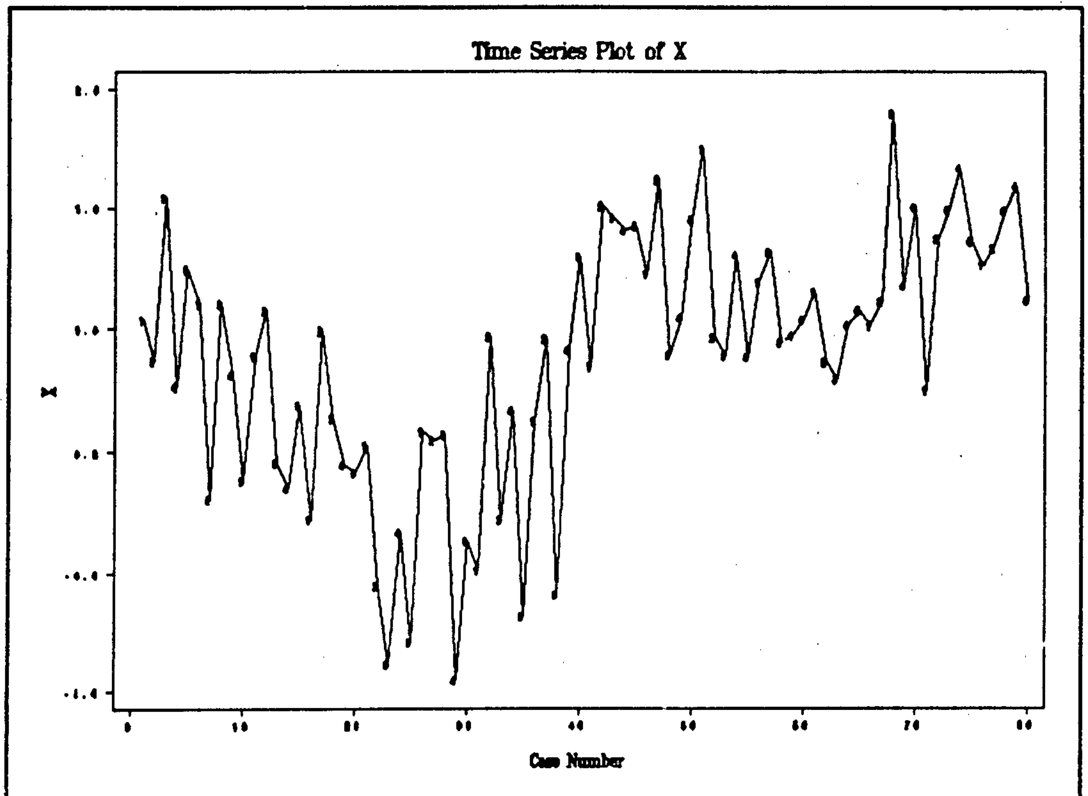
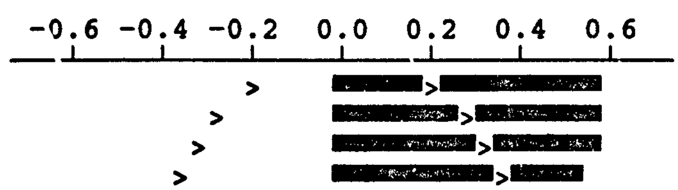


Figure D2. Time Series Plot of Horizontal Axis Impact Coordinates

A.5 Autocorrelation Plot for X

LAG	CORR.
1	0.558
2	0.570
3	0.550
4	0.514



MEAN OF THE SERIES 0.82527
STD. DEV. OF SERIES 0.82793
NUMBER OF CASES 80

The time series and auto-correlation plots clearly support the assumption of constant correlation of impact point coordinates.

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13. ABSTRACT *(Maximum 200 words)*

This thesis studies various engagement strategies for the Bradley Fighting Vehicle's 25-mm automatic gun firing APDS-T ammunition against a BMP-type target. The Army currently provides only the broadest guidance for the structure of the 25-mm point target engagement which results in the employment of an assortment of strategies throughout the Bradley community. The goal of this research was to determine if a best method exists. Bradley gunnery is a complex set commander/gunner interactions which can be difficult to represent with the analytic models commonly found in the literature. A model, based on the simulation methods used by the US Army Material Systems Analysis Activity (AMSAA), was developed to simulate the gunnery process in order to analyze the effects of firing a set pattern of single sensing rounds and multiple round bursts for the purpose of 'killing' the target. Analysis of variance techniques were used to characterize the effects of engagement strategies, precision and battlesight firing modes, and the burst on target (BOT) direct fire adjustment technique on the simulated Bradley gunnery process. Based on these results, conclusions and recommendations concerning the structure of the 25-mm point target engagement are discussed.

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